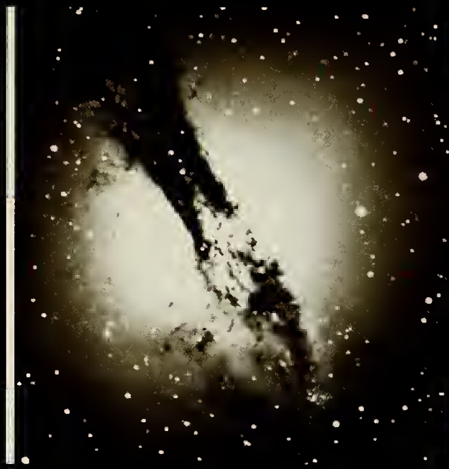
RESEARCH

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Environmental Research Laboratories



Contents

AMERICAN REVOLUTION BICENTENNIAL 1776-1976

RESEARCH

*"...studious inquiry or examination; esp: investigation or experimentation aimed at the discovery and interpretation of facts, revision of accepted theories or laws in the light of new facts, or practical applications of such new or revised theories or laws..."**

THUS A TERM we have from the Middle French retains its meaning, even in the present era of nanoseconds and GigaHertz, particles and waves, man-altered weather, continents adrift. Nothing fundamental has changed since the word was coined: research is still energized by intellectual sparking across the gap between the possible and the desirable, between that which we know and that which we would know.

As the act of research is applied to our physical environment, it becomes universe-sized, evoking interactions between our planetary home and the larger world of cosmic energy and distant stars, human efforts to comprehend and change natural processes, explorations of both real and mathematically simulated oceans and atmospheres, and the use of unfamiliar eyes and ears, sights and sounds, to observe conditions in the environment.

This is the work of the Environmental Research Laboratories, one of the major elements of NOAA, the U.S. Commerce Department's National Oceanic and Atmospheric Administration. The antecedents of these laboratories are the former Central Radio Propagation Laboratory, and research efforts in the former Weather Bureau and Coast and Geodetic Survey. When the Environmental Science Services Administration was formed in 1965, these functions became the Institutes for Environmental Research and later ESSA's Research Laboratories. Then, with the formation of NOAA in 1970, this research arm became the present Environmental Research Laboratories, with headquarters in Boulder, Colorado, and laboratories around the Nation. These laboratories — and projects conducted outside NOAA under grants, contracts, and such efforts as the NOAA-University of Colorado Cooperative Institute for Research in the Environmental Sciences — constitute centers of action for the new science and technology we use to describe, simulate, monitor, predict, and modify the world around us.

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Winds From the Sun

THE PLANETS SWEEP through a thin wind of energetic particles and radiation as they turn down their orbital courses around the sun, each influenced profoundly — and differently — by the flow of energy and matter from this nearby star. And this solar wind, in its turn, has larger interactions of its own, for it meets and mingles with the cosmic energy radiated by other stars, other galaxies.

This complicated web of solar and interplanetary forces and fields has come to be the subject of increasingly intensive study, given impetus both by man's spaceward stride and an improved understanding of the strength of the solar-terrestrial bond. But the Environmental Research Laboratories' effort in this field derives from a generation-old concern of the U.S. Department of Commerce for the down-to-earth matters of communication and navigation — bursts of solar activity disrupt some types of radio communication, and sun-triggered geomagnetic storms play havoc with magnetic compasses.

From those considerations, this effort has evolved into a wide-ranging investigation, centered in the Space Environment Laboratory and Aeronomy Laboratory. The field of study is a blend of basic research and applied technology, dealing with theoretical interplanetary, magnetospheric, and solar-terrestrial physics, the chemical and dynamic details of earth-sun interactions, the development of new instruments, methods, and computer techniques, and real-time data and space-disturbance warning services. The questions asked — and answered — range widely, from whether the atmosphere of Venus has an electrically charged region (an ionosphere) to the effect of geomagnetic storms on long power and communication lines, from speculations on the shape of the Jovian magnetosphere to collisions of subatomic and molecular particles in the earth's upper atmosphere.

The Space Environment

The research programs carried out by the Space Environment Laboratory are concerned with the solar-terrestrial environment as a sun-earth system, expressed in terms of strongly interacting subsystems. In this view, energy from the basic driving force, the sun, is coupled through the interplanetary medium to the near-earth environment, the region stretching from an altitude of about 50 kilometers to a distance of some 10 earth radii, the outermost boundary of the geomagnetic field. By illuminating the components of these subsystems, and by defining their virtual infinity of interactions, the laboratory hopes to find some accommodation between processes in the space environment and the earthbound and spaceborne activities of man.

The development of a physical solar-terrestrial environmental model (STEM) is one of the long-term goals associated with this work. STEM is an ambitious modeling program using results obtained by researchers here and abroad. Consisting of six "sub-models" — models which numerically simulate the solar flare, propagation, interplanetary medium, energy transfer into the magnetosphere, the magnetosphere itself, and ionospheric interactions —STEM will permit scientists to simulate the physical processes that shape the solar-terrestrial environment and govern its dynamics, from the solar surface down into the earth's upper atmosphere and ionosphere.

Studies of interplanetary and magnetosphere physics are directed toward a fuller understanding of all aspects of the transfer of energy and particles from the sun to the near-earth environment and ultimately into the earth's atmosphere. Several general investigations in this area deal with the interplanetary medium and the flow of particles through this medium, transfer of energy and momentum from the interplanetary plasma into the magnetosphere, and, finally, the dynamics of the magnetosphere-ionosphere-atmosphere system itself. Physical models of interplanetary and magnetospheric processes are being developed from this research and used to follow — and, eventually, will be used to predict — the evolution of such processes.

This investigation has produced a dynamic model of the magnetosphere — the "envelope" of magnetic field lines surrounding the planet in space — that yields time variations and the topology (or geometry) of the magnetosphere from a single parameter input. Other successful modeling efforts include those treating the behavior of charged particles — protons and electrons — trapped in the magnetosphere, and their interactions with solar protons, the equatorial currents set up around the earth by magnetic storms, and other magnetospheric processes.

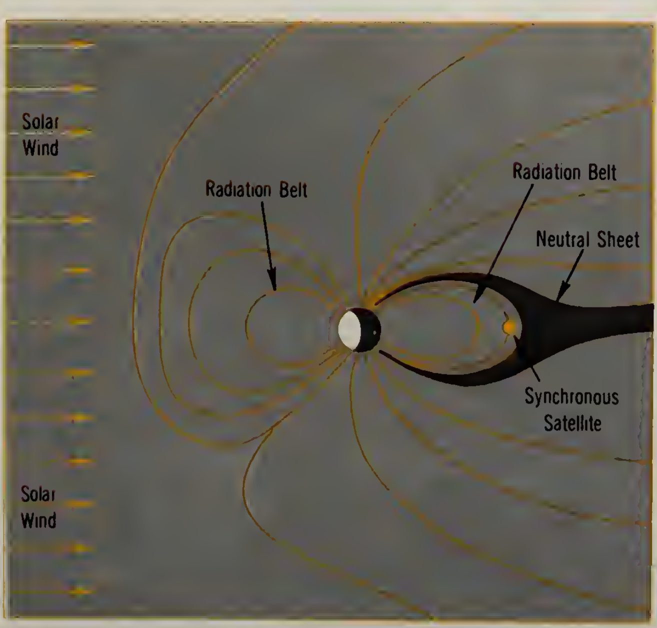
Additional models attempt to describe interactions between the solar wind and the thin energetic winds "blowing" earthward from other stars and galaxies. One such model places initial interactions at only 3 Astronomic Units (AU)*, where solar-wind protons are apparently heated by interactions with hydrogen atoms in the interstellar gas. Then, somewhere beyond the orbit of Pluto, the supersonic solar wind encounters intersellar thermal plasma and slows to subsonic speed, setting up a shock wave where the two electrically charged media meet. Data from such interplanetary missions as NASA's Pioneer 10 and 11 Jupiter probes are being used to evaluate this type of model, as well as those which laboratory scientists are using to infer probable interactions between the magnetospheres of other planets and the solar wind.

This effort includes the analysis of data obtained from a variety of scientific satellites and sounding rockets.** A related series of sounding rocket launches (including cooperative efforts with the University of Bergen, in Norway) probes the region between balloon and satellite altitudes, providing data from which detailed studies of the ionosphere and low-altitude region of the magnetosphere can be made.

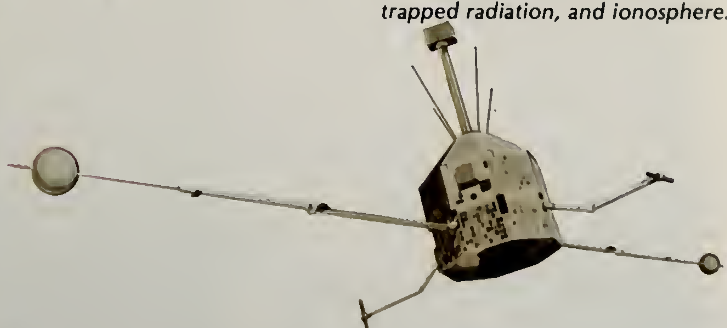
A ground-based study of plasma irregularities in the interplanetary medium is also under way. This uses large-area antenna arrays to study the scintillations of stellar radio sources that are introduced when the radio wave passes through plasma irregularities within the solar system.

The great solar events of August 1972 provided a unique opportunity to test theories concerning the propagation of solar plasma and shock waves in the interplanetary medium. Numerous spacecraft, ranging in position from 0.7 to 2 AU, recorded the effects of this solar outburst. In addition to satellite observations, the brightness of comets, located at even greater heliocentric distances, and radio emissions from Jupiter (at 5.25 AU) are being studied to detect the arrival time of the shock wave at those positions. In general, excellent comparison has been obtained between these observations and theoretical models.

Researchers in the Space Environment Laboratory see a deep involvement between the National Aeronautics and Space Administration's space shuttle program and a proposed experiment in which cold plasma would be injected at



The complex space environment that NOAA scientists are learning to simulate and predict includes the sun, interplanetary space, and the earth "subsystem" of planet, magnetosphere, and atmosphere. The spacecraft below one of NASA's small scientific satellites, or S³'s, used to gather data on interactions between the solar wind, the earth's magnetosphere and belts of trapped radiation, and ionosphere.



*The Astronomic Unit (AU) is the mean distance of earth from the sun, about 92.9 million miles or 150 million kilometers.

**High-quality data concerning the magnetic and particle environment come from the Pioneer, IMP, and NOAA series of satellites, together with the OGO-6, S³, and HELIOS solar probe. In the future, data from instruments aboard the ATS-F, TIROS-N, SMS/GOES, and the Mother/Daughter IME satellites are anticipated. IMP is the acronym for Interplanetary Monitoring Platform, OGO, for Orbiting Geophysical Observatory, ATS, for Applications Technology Satellite, SMS/GOES for Synchronous Meteorological Satellite (the NASA designation) and GOES for Geostationary Operational Environmental Satellite (the NOAA designation). IME refers to the International Magnetospheric Explorer, Mother/Daughter to two of the satellites in this system. S³(or S-cubed) designates the Small Scientific Satellite, designed specifically to investigate the cause of geomagnetic storms and substorms. NOAA satellites (also called ITOS, for Improved TIROS Operational System) are operational polar-orbiting environmental spacecraft; TIROS, an acronym for Television Infrared Observational Satellite, continues to evolve, with TIROS N a third-generation operational satellite planned for the NOAA series.

geostationary altitudes (6.6 earth radii) in order to trigger naturally occurring magnetospheric plasma instabilities. The result of such stimulation would be the scattering of the surrounding energetic trapped particle population down the field line into the ionosphere. The resulting ionospheric disturbance should be easily detected by ground instrumentation and could result in a visible aurora. Such active modification projects, as opposed to the present program of passive observation, are considered necessary tests of theoretical models.

Research in ionospheric physics in the Space Environment Laboratory is concerned with developing an understanding of the boundary conditions to the ionosphere, and the resulting dynamic behavior of the ionosphere and its interactions with the upper, neutral atmosphere. These programs investigate spatial and temporal irregularities in the ionosphere, interactions between the ionosphere and the magnetosphere, and the response of the ionosphere to natural and artificial transient energy inputs.

Much of the effort is concerned with models and theoretical studies. A theoretical model of the equatorial F-region — the highest layer of the ionosphere — has been developed that accounts for the anomalous distribution of electron density near the equator. Other modeling efforts here include the modification of one developed at Stanford Research Institute, that predicts ionospheric scintillation effects which perturb satellite communication systems, and a "standard" solar flux model for moderate solar conditions in the 1,000 to 3,000 Ångstrom range.

Another describes the increases and decreases of electron densities during a magnetic storm. This model is based on a point heat-source located on the noon point of the auroral oval, from which the disturbance emanates. In this imaginary system, the earth's rotation causes the source to move faster than the disturbance, setting up a "wake" which sweeps across the planet. A "storm front" is established along the envelope at which disturbances are focused, while ahead of the front, a wind is set up which lifts the plasma to levels of low electron loss, giving rise to the positive phase. At and behind the front a change of chemical composition occurs, causing enhanced electron loss and so producing the negative phase.

The lower thermosphere — the region from 80 to 150 kilometers' altitude — is also the subject of theoretical study. Present investigations here are evaluating the major sources and sinks of thermospheric energy, and their variations with season, latitude, and other factors.

Operational space environment monitors are continually being improved, as more sophisticated instruments are placed aboard the new generations of environmental satellites. A Space Environment Monitoring (SEM) subsystem in the SMS/GOES series is designed to provide data on energetic particles, solar X-rays, and the earth's magnetic field at geostationary altitudes. Working closely with the NASA program office, the laboratory provides liaison and guidance to space agency contractors responsible for the SEM portion of the SMS/GOES system. It also designed a telemetry receiving system and on-line data-processing and display system for SEM data.

Experimental ionospheric observations are made using a modern digital ionosonde. Ionosonde measurements will be compared to the *in situ* measurements of the Atmosphere Explorer satellite in a cooperative program with NASA. The ionospheric physics area provides the principal investigator for the ATS-F satellite radio beacon experiment which will be in a data collection stage in 1974 and 1975.

A comprehensive particle-monitoring subsystem has been specified for the TIROS N and follow-on operational satellites in that series. This flight instrumentation is being developed internally by the Space Environment Laboratory, working with contractors in other laboratories and in industry.

Support for the ATS-F project consists of evaluating and checking the assembled experiments — one flight unit and one flight spare — prior to the 1974 launch of this satellite. It also involves development of basic specifications for the satellite radio beacon transmitter, liaison with NASA, and contractor liaison during construction of the unit. A comprehensive receiver for beacon transmissions is being constructed and checked out under the ground sector of the program funded by the ATS-F project. The receiver and data-acquisition system will use a minicomputer both for receiver control and calibration and data acquisition.

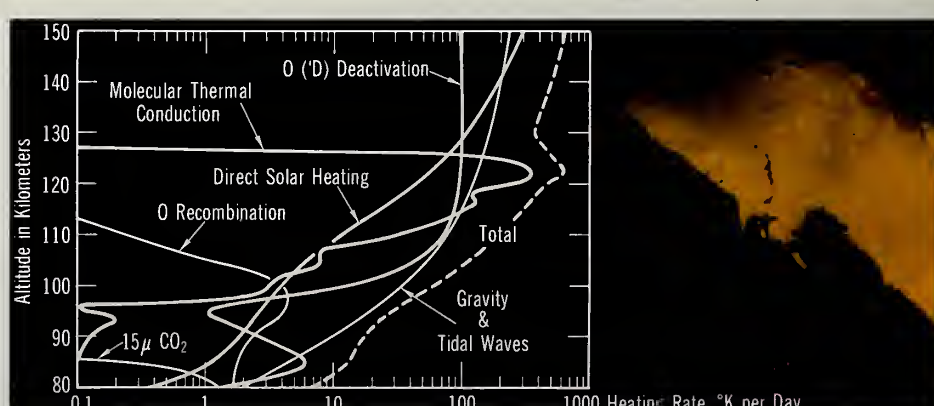
IME experiment support has included production of major portions of the proposed technical and management sections and project liaison with NASA during initial program definition. The opportunity for this experiment, which involves placing a satelliteborne solid-state detector aboard the spacecraft, is provided under the joint sponsorship of NASA and ESRO, the European Satellite Research Organization, program to launch three satellites, the first two of which are scheduled for a January 1977 launch.

Work is also underway to develop several new on-board techniques for data-processing, including multidimensional pulse-height analysis. In addition, it is intended that several integrated circuit modules will be developed within this program to improve system performance for certain critical pulse-analog and pulse-height-discriminator portions of the experiment. Time-of-flight measurement techniques are being investigated as a possible means of improving heavy ion species identification.

A project funded by the Department of Defense aims at developing systems for measuring the inplace electromagnetic properites of rocks and soil at MegaHertz frequencies. One byproduct of this instrumentation effort has been the development of a programmable, calculator-controlled network-analyzer system.

Instrument development to improve sounding rocket payloads is also underway. Experiments made in cooperation with the Norwegian Government used sensors for four auroral research flights. In the mid-1970's, a complete *Javelin* payload will be integrated with sensors from the Space Environment Laboratory and other research organizations to use in the sounding rocket program.

Understanding how energy and matter are exchanged in the highly interacting magnetosphere and ionosphere is a critical element of the Space Environment Laboratory investigation. These curves show typical heating-rate profiles for most of the major heating sources in the 80-to-150-kilometer region. The sun and man photograph was taken in hydrogen alpha light by NOAA's solar observatory in Boulder, Colo.



The Solar Watch and Warning

PRIMITIVE SOCIETIES are untouched by events on the sun — as long as this star produces the daily ration of light, heat, and beneficial radiation; as long as its ecliptic steers the seasons, there is no need for non-technical man to give it much attention. But for our complex, high-technology culture, there is nothing remote about the distant storms that sweep the sun. In fact, the solar influence grows year by year, and deepens as we learn more about environmental interactions in this sun-dominated corner of the galaxy.

The sun goes through approximate 11-year cycles of alternately increased and diminished activity. During the several years around the time of peak activity, flares occur that may cover an area on the sun many times the total surface of the earth. These great outbursts of energy in the solar "atmosphere" (chromosphere) are usually associated with groups of sunspots, and both spots and flares appear to be closely linked to changing magnetic field polarities on the sun.

The Space Environment Services Center, the forecasting and warning arm of the Space Environment Laboratory, monitors the solar surface continuously, providing real-time information on conditions in the space environment to civil and military managers of sun-sensitive activites. When solar activity increases, the Center issues timely reports and forecasts of possible future activity and probable geophysical effects.

These can be profound. The prompt X-rays strike into the upper atmosphere, altering conditions along sun-facing ionospheric paths used for some types of radio communications. Solar particles — energetic protons and electrons — reach the earth environment several days later, interacting with the upper atmosphere over the polar regions to produce auroral displays. At the same time, strong, irregular electrical currents flow in the magnetosphere and polar ionosphere, changing the magnetic field at the earth's surface.

Electrical power systems in northern latitudes of the United States are sometimes interrupted during geomagnetic storms, which may induce strong currents in long electrical transmission and communications lines, tripping circuit breakers and burning out transformers. In the past, geomagnetic storms have been responsible for power blackouts in large cities as well as extensive interruption of long-distance telephone communications. As power and communication nets become intricate and more heavily laden, unexpected geomagnetic storms may very well increase the incidence of power disruptions, especially during the "brown-outs" which have become routine in the northeastern United States. Utilities and telephone companies have joined the ranks of solar forecast clientele, and have begun research aimed at explaining the causes and effects of their unique and critical relationship with the sun.

Communications problems caused by solar disturbances helped create the present forecasting service, and continue to be a prime concern at the Space Environment Services Center, for military and civilian programs require real-time reports and forecasts concerning solar effects on high-latitude radio communications. A Memorandum of Agreement is in effect between the Commerce Department and the Department of the Air Force for cooperative space environmental support activities between NOAA's Environmental Research Laboratories and the Air Force Global Weather Central at Offutt Air Force Base, Nebraska, and the Aerospace Environmental Support Center, at Ent Air Force Base, Colorado (both of the Air Weather Service). Cooperative activities under this agreement include joint Air Weather Service-NOAA staffing of the Space Environment Services Center at Boulder and of the laboratory's High-Latitude Monitoring Station at Anchorage, Alaska, sharing of data and data-transmission facilities, joint observing programs, and operation of the global network of "solar patrol" observatories.

Extensive communication forecast and monitoring services are also provided to such northland users as the Federal Aviation Administration, Federal Communications Commission, Federal Bureau of Investigation, State of Alaska Communications System, Bureau of Indian Affairs, the oil industry, and various fisheries interests.

A literal "space weather service," the Space Environment Services Center monitors conditions on the sun and the geophysical effects of increased solar activity. Manned space missions like Skylab, at left, are among the Center's major clients.

Very energetic solar particles, arriving as soon as 20 minutes after a flare, can penetrate the polar atmosphere to heights at which supersonic transports fly. At times of great flares, such particles may pose a radiation hazard to passengers aboard these aircraft. Accordingly, regular monitoring and forecasts of energetic particle events are supplied to the *Concorde* supersonic transport program, to permit aircraft to take evasive action in the event of a hazardous solar flare.

Human vulnerability to the stream of energy from an active sun increases greatly outside the atmospheric shield, and providing timely data to the National Aeronautics and Space Administration in support of manned space missions has been one of the Space Environment Services Center's primary reasons for being. Over the early years of space exploration, the NOAA facility has helped keep the solar radiation hazard to manned space missions to a minimum through forecasts of these events and accurate predictions of the intensity of the flare-produced proton streams. These forecasts will be of still greater value as manned missions last longer, and the exposure of astrocrews increases.

The Center has also helped the space program achieve certain research goals. For example, the observation schedules for the Apollo Telescope Mount — an array of six solar telescopes — aboard Skylab were developed from data furnished by the Space Environment Services Center and cooperating observatories, permitting maximum use of this unique solar observatory circling outside the atmosphere.

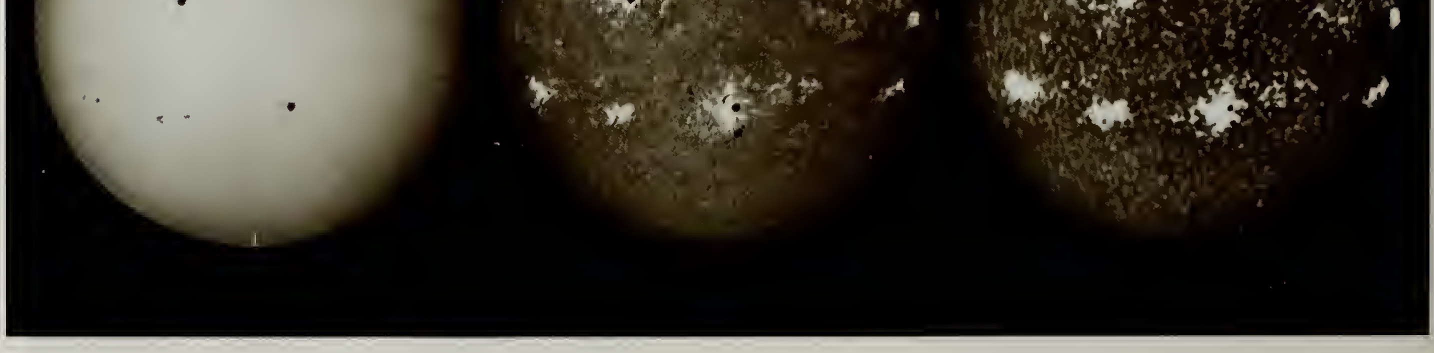
A real-time data service is a crucial element in this solar monitoring and forecasting activity, and includes the High-Latitude Monitoring Station in Anchorage, where various ground-based radio experiments provide information on the state of the Arctic ionosphere and geomagnetic field; and the data display systems in the Services Center and an observatory at Table Mountain, near Boulder. Data received at Anchorage and Table Mountain are processed in real time by small computers and relayed to the forecaster. In addition, solar proton and magnetic data (through the courtesy of Dr. G. Paulikas, Aerospace Corporation, and Dr. P. Coleman, UCLA, respectively) are received from a satellite in geostationary orbit over the Pacific Ocean, and solar radio and ionospheric radio experiment data come in from the Table Mountain observatory, as do solar proton, solar X-ray, and magnetic data from the GOES spacecraft.

The Space Environment Services Center Maintains a real-time solar geophysical data base in a time-share computer accessible to users via telephone and teletype. Included in this system are data collected from a global network of radio and optical solar telescopes; data from satellites (including the Pioneers, VELA, ATS-1, GOES, NOAA) providing information on solar X-rays, solar protons, the solar wind, and the magnetic field; geomagnetic, ionospheric, cosmic ray, and neutron data from ground observatories; and three-day forecasts of the level of solar activity, including percentage probabilities of large flares, geomagnetic conditions, and average solar radio flux.

Other data products available from the Center include brief rèsumés of data excerpted from the data base, alerts and warnings concerning major solar geophysical events, and weekly data summaries with hydrogen alpha photographs and other graphic material. Publications include special reports on such significant events as the August 1972 solar flares and their geophysical effects.

Recent benefits obtained from operations-oriented research include an enhanced ability to predict geomagnetic storm activity from direct observations of interplanetary magnetic-field sector boundaries by space probes, and indirectly, from observations of the geomagnetic field at high and polar-cap latitudes. Synoptic maps of the large-scale magnetic fields of the sun are being constructed, based on the chromosperic structures photographed in hydrogen alpha light by the solar patrol observatories. These maps, which can be updated in real time, provide important information on the evolution of solar activity, and definite clues to the possibility of major flares and the propagation of solar disturbances to the earth.

Observing the sun at different wavelengths emphasizes different features on the solar surface. The three solar discs shown here were photographed simultaneously in (from left) white, hydrogen alpha, and calcium light.



Collisions and Thin Chemistries

For the space Environment Laboratory the processes which concern researchers begin in the sun and reach out through interplanetary space to the environment of earth, and the activities of men. The work of the Aeronomy Laboratory, on the other hand, tends to be more planet-centered, dealing mainly with the thin outer shells of meager gases and electrified particles which mark the region in which atmosphere diminishes and finally vanishes into the virtual vacuum of space. The chemistry and dynamics of this nebulous region, the meteorology of the high upper atmosphere, and the relationships between events there and man's ability to communicate over distance are central figures in this laboratory's programs.

Theoretical solar-terrestrial and plasma physics studies occupy part of the Aeronomy Laboratory's effort, and deal mainly with the regions of interaction between the ionosphere and the outer reaches of the earth's magnetosphere, and with how energy and matter are transmitted, exchanged, and transformed in the ionosphere. Recent experimental and theoretical studies have shown that the ionosphere plays a major role in governing the interaction between the solar wind and the earth's atmosphere, leading to the dramatic phenomenon of the aurora and the attendant disruptive effects on radio communications and power lines. A model that incorporates this coupling between the ionosphere and the outer reaches of the magnetosphere is under development, and promises to explain the events leading up to major auroral disturbances in a quantitative way.

The D-region of the ionosphere — the lowest ionized layer — provides the basis for the propagation of the low-frequency radio waves used for worldwide oceanic navigation systems, and is also responsible for absorption of the higher frequency radio waves used for radio and marine communications. The laboratory is working on a model that simulates this important ionospheric region under both natural and perturbed conditions, and that will eventually include a detailed set of the influential chemical and dynamic factors operating there.

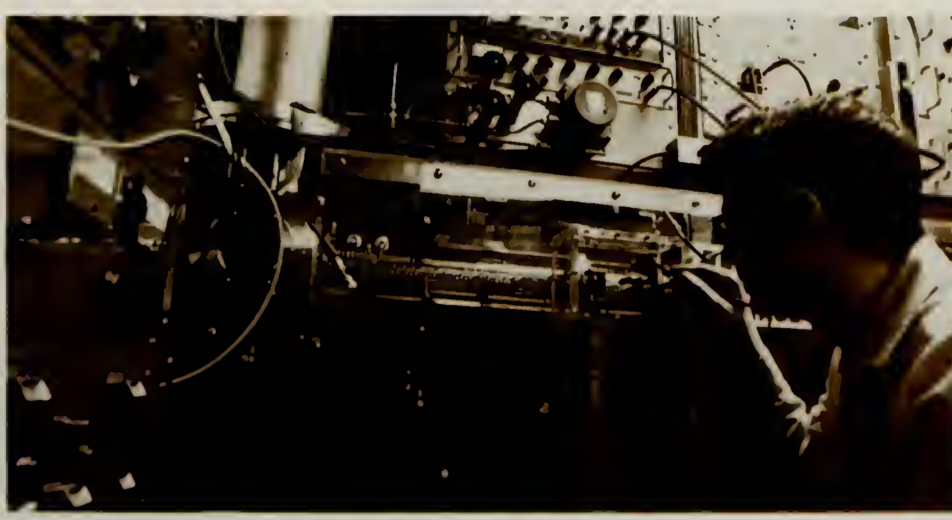
Plasma turbulence has a direct effect upon telecommunications, radar, and the distribution of both natural and artificially produced (e.g., radioactive) ionization in the atmosphere. Such turbulence can enhance radio communications between points on earth by scatter propagation; but it can also seriously degrade radio communications between the surface and space vehicles. Accordingly, a general theory has been developed to answer questions concerning atmospheric plasma turbulence. Physically, this theory is based on the effect of turbulent electric fields on the perturbed trajectories of diffusing particles; the spectrum of turbulence is then determined by these perturbed trajectories.

Detailed theoretical studies have also been made of modifications of the ionosphere by intense radio transmission. A model has been developed that predicts large increases in resistivity and temperature following such transmissions, and changes of the electron distribution of the ionosphere during modification. Such changes, observed in experiments conducted by the Aeronomy Laboratory, the Space Environment Laboratory, and the Institute for Telecommunication Sciences (of the Commerce Department's Office of Telecommunications), are of great interest for telecommunications and defense purposes.

Experience with the ionosphere is being "exported" to lower levels of the atmosphere, and applied to the problem of air quality. Turbulent eddy diffusion is a dominant process in pollution dispersal, and this research will attempt to predict and model pollution-dispersing processes and interactions. Aeronomy Laboratory researchers are also exploring how techniques developed to predict the behavior of thin, charged gases can be applied to the urgent problems of air quality in the atmospheric zone of life.

Research on atmospheric processes and composition in the Aeronomy Laboratory focuses on the region where

The interaction of the electrically charged ionosphere and the neutral (uncharged) atmosphere are simulated in the Aeronomy Laboratory's flowing afterglow facility, in which ionized and neutral gases are mixed and their reaction-rate constants are determined as functions of temperature and other parameters.



atmosphere and ionosphere mix, interact, and are mutually transforming. This work studies the collisions and chemical reactions of ionized and neutral elements in the high upper atmosphere and lower portions of the ionized D-region, the concentration and variability of atmospheric gases above the stratosphere, and the fundamental particle wave processes — and improved methods of measuring them — of this atmospheric region.

Experimental and theoretical basic research on atomic and molecular processes in the earth's atmosphere emphasizes measurement of ionospheric ion-neutral reaction rate constants. The complex reaction schemes which convert positively charged molecular oxygen (O_2^+) and nitric oxide (NO^+) ions to hydrated hydronium ions in moist atmospheres have been studied in great detail and are being extended. These studies have been applied to an analysis of D-region positive ion chemistry. Stratospheric and tropospheric positive ion reaction schemes, including the important effects of ammonia, have also been measured.

Detailed negative ion reaction schemes have been determined in this laboratory and are forming the basis for analyzing the first *in situ* D-region negative-ion composition measurements. The flowing afterglow technique has been extended to measurements of electron-attachment rate-constants and applied to studies of electron attachment to several metal oxides. This work is important for understanding the behavior of ionization in the wake of space vehicles re-entering the atmosphere. Tropospheric negative-ion reaction schemes have been studied, including the effects of trace sulphur dioxide (SO_2) on the ion composition.

A large amount of basic molecular data has been derived from the ion-molecule reaction studies, including bond energies, electron affinities, ionization potentials, and equilibrium constants. The electron binding energies of the important D-region species NO_2 and NO_3^- (nitrogen dioxide and nitrogen trioxide) have been precisely measured.

A new program of atmospheric neutral reaction kinetics is under development. Using sophisticated laser techniques developed in the adjoining National Bureau of Standards laboratory, sensitive methods of detection of the radicals OH and HO_2 and also HCO are now being used to study reaction kinetics involving these species. This work is being carried out in collaboration with a National Bureau of Standards group.

In the laboratory's atmospheric composition studies, research includes the measurement of chemically active neutral constituents in the mesosphere and lower thermosphere, and the determination of the variability of the major thermospheric gases. An experimental technique to measure atomic oxygen has been developed which takes advantage of the oxidizing potential of atomic oxygen. A thin film of silver, used as a resistive element in an electric circuit, is exposed to the atmosphere and the change in resistance due to oxidation is related to the ambient atomic oxygen density. Data from several rocket flights with this instrument have shown substantial latitudinal variations in the oxygen density.

In order to investigate the major gases, an occultation technique is being employed where atmospheric absorption is obtained by viewing the sun through the atmosphere at twilight with satellite-borne instruments. Data from the Naval Research Laboratory satellite SOLRAD 8 show substantial day-to-day and large seasonal variations in molecular oxygen in the lower thermosphere. Data from SOLRAD 10 and OSO 6 are being analyzed and data from Skylab will be analyzed as it becomes available.

The chemistry and physics giving rise to the vertical and global distributions of the various gases are also being studied. Emphasis in the past has been on photochemistry; however, increasing effort is being placed on understanding the transport processes. Because the distributions of the gases depend on the temperature structure, some future effort will be placed on understanding the thermal balance in the atmosphere.

Studies are carried on by the Aeronomy Laboratory of particle and wave processes, especially the fundamental particle and wave processes that are important to atmospheric phenomena such as aerosol physics, wave propagation, collision processes, and wave-particle interactions. The development and use of measurement techniques for determining atmospheric properties is part of this work.

A systematic development of the kinetic theory of gases in the transition regime where the mean-free-path between collisions is neither large nor small has been started. There is no such systematic development available at present, although this regime is important in the upper atmosphere for vehicles interacting with the atmosphere, and in the lower atmosphere for particulate matter such as aerosols. A method for dealing with trace constituents in a gas under transition-regime conditions has been developed and is being applied to the calculation of airglow line profiles in the upper atmosphere.

Instruments at Fritz Peak, Colo., observatory are used to monitor airglow and other sky phenomena at altitudes of interest to Aeronomy Laboratory scientists. The scanning photometer at left and the photometer below are used to monitor airglow, sensing different colors as different filters are used. The atomic oxygen sensor shown on the facing page was developed to obtain data at auroral altitudes.

Structure in the radio-frequency resonances observed by radio sounders on satellites near the plasma frequency has been shown to depend on electron temperature and provides a new method of measuring it. Interest in this explanation and in the geophysical use of resonances has led to the development of an advanced sounder, which was launched on a rocket to an altitude of 650 kilometers and obtained enough data to show that the resonances behaved consistently with predictions. A more sophisticated sounder planned for an equatorial launch should provide a more conclusive validation of the theory: it will also test the use of such observations as a measurement technique for electron density and temperature (both along and across the field) along with drifts and magnetic field strength.

Laboratory studies are being carried out on the effect of the plasma parametric decay instability on the heating of plasma by strong radio-frequency fields. The instability has been positively identified and the threshold electric field required to excite the instability has been measured. This helps to explain the large observed heating rates of ionospheric plasma when the F region is irradiated by intense radio waves.

A discrepancy between two different techniques of measuring ionospheric ion temperatures has been resolved. Laboratory work and theoretical calculations show that non-uniformities in the grid plane of retarding potential analyzers have led to inferred ion temperatures that have been high by as much as 30 percent compared to radar backscatter measurements.

A theory for taking into account the effect of satellite electrical potential on inferred ion and electron densities in the exosphere has been developed and applied to satellite data obtained through the plasmapause. Previous ion densities obtained without taking this effect into account have been incorrect at times by as much as an order of magnitude.

Optical observations of ionospheric phenomena apply a variety of sensitive and specialized detection methods to problems concerned with the energy balance, composition, and dynamics of the upper atmosphere. Although major emphasis is placed upon observation and interpretation of naturally occurring optical emission from the atmosphere, the program also includes detection of emission induced by artificial heating of the ionosphere by radar, and laboratory studies in photochemistry when required for interpretation of field measurements.

In addition to a major program of measurements at the Fritz Peak Observatory, Colorado, infrared studies of aurora and airglow are performed on an Air Force jet, and infrared studies bearing on the Martian ozone abundance are planned in conjunction with the Smithsonian Observatory in Arizona. In almost every line of investigation the important problems demand instruments of great sensitivity and spectral purity which cannot be commercially obtained — they must be designed and developed within the program itself.

Variations in molecular oxygen in the thermosphere (the region of increasing temperatures from about 80 to 200 kilometers' altitude) and ozone abundance in the mesosphere (50-80 kilometers) as reflected in twilight emission features from atomic and molecular oxygen are under study here. The large seasonal and geomagnetic variations observed seem to reflect changes in the turbulent transport rate near 100 kilometers, a quantity which plays a fundamental role in determining upper atmospheric composition and thermal balance.

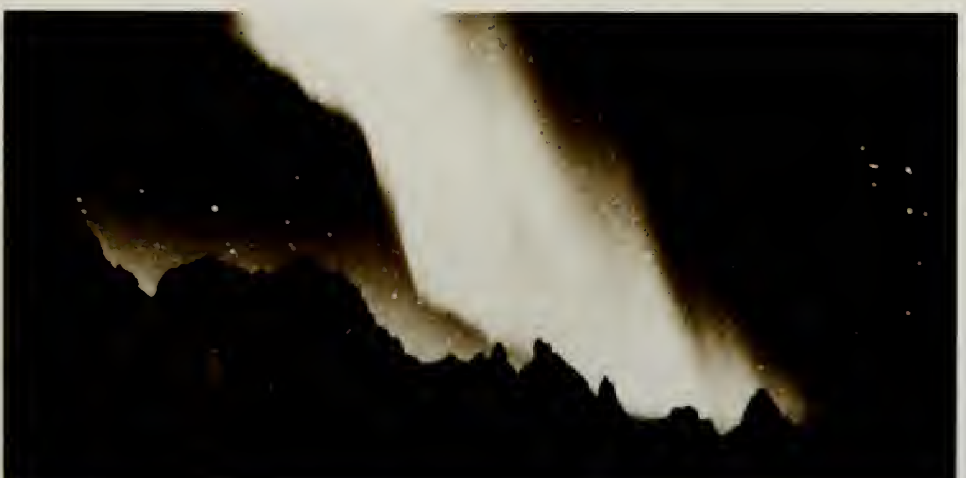
Thermospheric neutral winds and temperature are being monitored directly by studying the shape and wavelength shift in airglow emission lines with high-resolution interferometers. These two fundamental quantities, which can be determined in both the 100- and 300-kilometer altitude regions separately, are basic to an understanding of thermospheric dynamics and thermal structure, and are of great significance in ionospheric dynamics.

Optical studies, both separately, and in combination with incoherent radar backscatter studies, reveal major changes in thermospheric composition in geomagnetically disturbed periods. Infrared auroral studies based on aircraft observations show major emission not directly resulting from particle bombardment. This may reflect a significant alteration in the composition and chemistry at auroral altitudes. Related studies of subauroral red (SAR) arcs yield information on the morphology and energy flow from the outer plasmasphere under disturbed conditions.

Radar studies are being conducted of ionospheric irregularity structure in the equatorial and auroral E regions, and the equatorial Spread F. The equatorial investigations have been conducted primarily at the Jicamarca Radar Observatory in Peru, while the auroral observations are made at field sites in Alaska. Many of these experiments use a portable radar system developed within the laboratory.

The investigations are concerned primarily with the physical processes that produce ionospheric irregularities, while additional emphasis has been given to using the results to obtain a better insight into ionospheric coupling with both the magnetosphere and atmosphere. These same techniques have also been applied to obtain the "radar spectral signature" of various species of birds as an aid in their identification on airport radar systems.

Study of the physical processes in the ionospheric F region is carried out using ionospheric and nightglow data obtained at Jicamarca and near Boulder. Special attention is given to the physics of processes of recombination and nightglow excitation. A new radar in a canyon at Sunset, ten miles west of Boulder, is being used to study motions in the troposphere, stratosphere, and mesosphere, using a technique developed at Jicamarca.



University of Bergen, Norway, Photo

Weather and the Hand of Man

ONLY THE ALCHEMIST'S dream of transmuting base metals into gold equals the perennial ambition of those who would comprehend the processes we call weather — comprehend them, predict them, even change them. For the alchemist the search continues. But atmospheric scientists have pushed their disciplines to within a generation of realizing the largest of their "impossible" objectives. Much of this progress has come in the efforts of science to understand and mitigate the atmosphere's more violent offspring — the turbulent cumuli of tropical skies; squall lines and their destructive cavalries of lightning, thunderstorms, and tornadoes; hurricanes; and the great cyclonic systems that sweep the continent with entire families of lesser, but violent events. Investigators in what are now NOAA's Environmental Research Laboratories have helped with this pioneering work.

The Atmospheric Physics and Chemistry Laboratory, in Boulder, has done much to define the roles and populations of atmospheric constituents and to apply lessons learned in earlier weather modification projects to the modification of large-scale storm systems. It has also developed methods which may be able to suppress destructively intense lightning discharges.

The Experimental Meteorology Laboratory in Miami has brought tropical cumulus cloud-seeding techniques to a point where they have been applied quasi-operationally in a series of drought-breaking storms, and where research has begun to focus on the fundamental causal relationships in cloud seeding and cloud modification. The National Hurricane Research Laboratory, also in Miami, has led the development of methods of hurricane modification — aimed at the reduction of destructively high winds and storm surge, not the total suppression of hurricanes — to the threshold of operational utility. The National Severe Storms Laboratory in Norman, Oklahoma, is learning to read the extremely well-kept secrets of the tornado and its havoc-playing parent, the severe thunderstorm.

Airborne, instrumented platforms are required to enter the rugged laboratory of the atmosphere. The Research Flight Facility, based at Miami International Airport, provides the squadron of research aircraft and their uniquely experienced crews, while a Boulder-based effort seeks to arm the new generation of NOAA aircraft with the best airborne data systems available from present technology.

Art Into Science

There was a time in the United States when the business of altering the weather was best known for its early practitioners, the fast-talking rainmakers whose bizarre apparatus and ornate wagons roll through American lore and literature. That view has given way before the mid-century advances of weather modification as a science. Today, there is consensus among the distinguished scientists and engineers who have been attracted to this field that few meteorological developments would be so generally beneficial. There is also general recognition that the art of weather modification has, over the past generation, become a science, although not yet an exact one.

What seemed insurmountable problems a relatively few years ago have now been either solved or greatly simplified. In the sense that scientists know approximately what their weather modification project will do, most of the broad technical problems have been resolved. There *is* such a thing as operational weather modification today, most of it in the growing band of private weather-modifying organizations.

There are still many unknowns. It is one thing to know what is going to happen in a general way, and quite another to know precisely what will happen, when, where — and why. So that the trend and tone of such research in NOAA changed in the early 1970's as objectives evolved from trying to get a little more rain or a lighter kind of snow or smaller hailstones, to learning the detailed causes and effects behind these results and their broad geophysical implications. Also in this period of change, NOAA scientists began extending the weather modification expertise gained at one scale of time and motion, in one geographic location, to processes at other scales and latitudes.

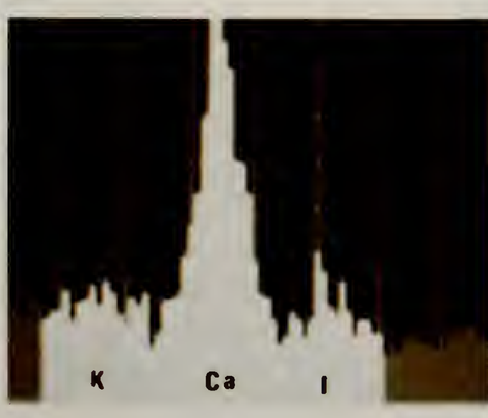
Most present-day weather modification projects use generally similar techniques of cloud seeding to achieve different results. The principle of cloud seeding is that water tends to remain in supercooled liquid state at temperatures far below freezing, unless it has a suitable "platform" to coalesce around — a sublimation nucleus. To freeze supercooled water, an agent introduced into the cloud must either lower temperatures sufficiently for water to freeze spontaneously (dry ice does this) or provide an ice-like, crystalline nucleus (like silver iodide). The latter is the seeding agent used in most of NOAA's work, dispensed by a slow-burning solid pyrotechnic whose exhaust product is a silver-iodide cloud.

An attendant effect of seeding is to reach into the stored heat energy carried by water in the atmosphere. Water absorbs or releases relatively large amounts of heat energy as it changes state — it absorbs heat as it changes from solid to liquid to vapor, and releases heat changing from vapor to liquid to solid. Thus, inducing supercooled water to freeze liberates significant amounts of this "latent heat," causing additional buoyancy and greater development of the cloud. This means that weather modification researchers can not only induce additional precipitation by causing supercooled water to freeze (and fall), but can also manipulate the distribution of heat energy to enhance or destroy the various equilibria of the system. In the weather modification work of NOAA's Environmental Research Laboratories, cloud seeding is used both to enhance and alter precipitation and to redistribute the energy fields of weather systems.

Another common feature of these efforts is that they deal principally with the turbulent creatures of the atmosphere, ranging from cumulus clouds, whose vertical motion (convection) makes them basic weather factories, to continent-sized extratropical storms. The broad objective is not to add to snowpack or increase rainfall, but to make the violent phenomena of the atmosphere accommodate themselves a little more to man. It is work that becomes less experimental season by season.

In the Atmospheric Physics and Chemistry Laboratory the emphasis in weather modification has shifted from obtaining specific short-term precipitation effects to the broader question of modifying entire cyclonic systems (see page 17), and to comprehending the interactions of seeding nuclei with the natural populations of nuclei and water in the atmosphere.

Much of the impetus behind the search for more fundamental knowledge of the forms and functions of atmospheric nuclei comes from the laboratory's experience in modifying winter storms over the Great Lakes. From 1968 to 1972, the laboratory conducted annual experiments over Lake Erie to determine whether the heavy downwind-shore snows experienced there could be beneficially redistributed. Theoretically, the introduction of silver iodide into the water-logged storm



An intensive study of ice nucleation in the Atmospheric Physics and Chemistry Laboratory is helping explain the poorly understood process by which ice crystals form around natural and man-introduced microscopic nuclei. At left, microscopic views of a typical ice crystal are shown with an X-ray analysis of their chemical composition across the nucleus. At right, filters from a western United States benchmark network are providing NOAA scientists with a regional ice-nuclei climatology, essential to understanding natural and artifical precipitation processes.

clouds over the lake would increase the number of freezing nuclei and produce large numbers of smaller snow crystals rather than the larger, naturally formed crystals. The smaller crystals would fall from the cloud more slowly and so be distributed over a wider area. Subsequent numerical modeling of the Lake Erie storms suggested that, by judicious seeding of the storms which move along the lake's long axis it should be possible to drop the major portion of precipitation back into the lake rather than on shore — that is, to use the techniques of weather modification as a water resource management tool.

The laboratory has also been conducting radiometric cloud physics missions before and after seeding attempts over the Great Lakes and the High Plains. Radiation budget observations and calculations were made of pre- and post-seeded cloud decks. Investigators found definite indications that strong local infrared cooling at the cloud top prior to seeding and the resulting overturning were a primary mechanism in sustaining the cloud deck in the absence of orographic (mountain) effects. Results obtained after seeding were less clear cut and displayed widely differing infrared cooling rates in the glaciated areas, directly related to interface temperature effects. Observations and calculations showed cooling rates (from cloudless conditions) in the glaciated area which resulted in additional cumulus development; in some missions, where seeded areas drifted over a warmer land surface, increased convection from below resulted in small cumulus development at altitudes between one and three kilometers. This research effort is increasing with the objective of determining the radiative budget effects caused by artificial cloud development or suppression, as part of the study of extratropical cyclone modification. It is also helping to explain the important question of areal and downwind development of seeded areas.

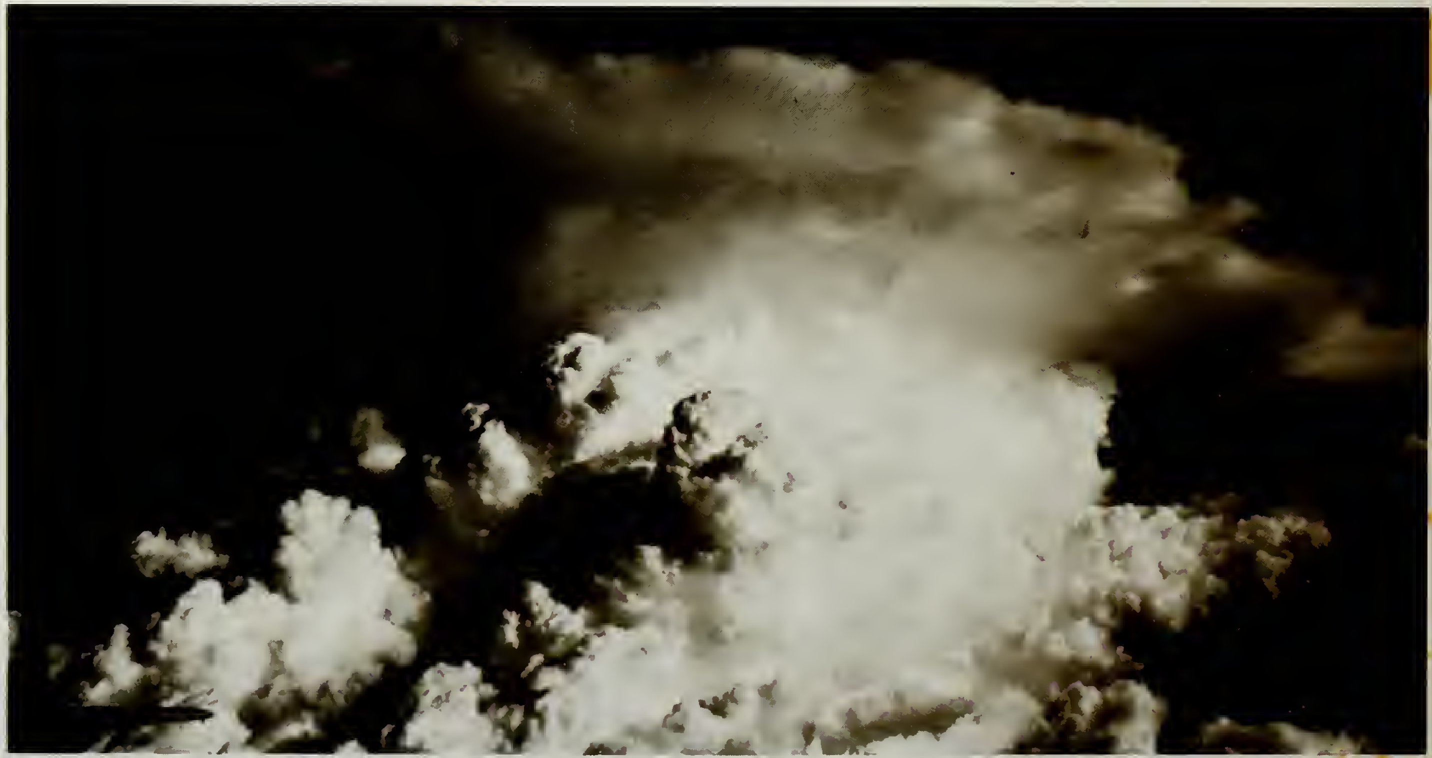
A strong effort in nucleation chemistry conducted by the laboratory seeks to explain the microscopically small parts and players behind the larger drama of weather modification effects. Here the objectives are to establish source and sink relationships and spatial distributions of nuclei in the atmosphere, develop criteria for distinguishing man-made from natural nuclei, and improve the fundamental understanding of how water vapor is converted into drops and ice crystals.

In the experimental portion of this program, methods have been developed to identify ice nuclei shape and composition using scanning electron-microscopy in conjunction with energy-dispersive X-ray analysis. An ice-nuclei network consisting of 24 sampling stations in the 17 western states (including Hawaii and Alaska) provides the specimens used for these measurements. These techniques should help explain the role of natural nuclei, and provide some indication of cloud seeding efficiency as expressed by the amount and distribution of seeding agent found in the sampled nuclei population.

Measurements made in Hawaii have established that the islands produce a variety of "artificial" nuclei, which affect Hawaiian weather and climate. Cane field fires are a source of ice nuclei, probably through the action of copper sulfide derived from the high copper content of the plants. Volcanic fumeroles produce cloud condensation nuclei through the action of hygroscopic sulfuric acid and sulfate aerosols. Even island vegetation is a source of aerosols, in this case a volatile organic one produced through photolytic polymerization of isoprenes (rubbery hydrocarbons) emmitted by ferus and ohialeua trees.

Gas chromatographic and mass spectrometric analyses made by the laboratory indicate that organic matter distributed in ocean water affects maritime cloud development and dynamics. As this organic material is carried into the atmosphere during the bursting-bubble process, it is polymerized into an aerosol by ultraviolet light, which retards the condensation efficiency of sea salt particles and so affects cloud condensation nuclei populations in the maritime atmosphere.

The laboratory has also developed, and applied to automobile exhaust, a laser spectroscopic particle analyzer which characterizes aerosol systems by measuring the specific absorption and emission of electromagnetic radiation near the aerosol source. Development of



this instrument will eventually result in a computerized data retrieval system in which spectroscopic aerosol characteristics will be related to the presence in various aerosol systems of Aitken, condensation, and freezing nuclei. The data will also provide information about the infrared absorptivity of aerosols and so permit a better evaluation of how they affect weather and climate through their interference with sun and sky radiation.

Other studies attempt to develop a better understanding of how ice nuclei act on water vapor, and of the effect of water vapor and temperature on the crystal structures of snowflakes developing from frozen droplets. These researchers are also trying to refine their evaluations of the effect of aerosols on climate, relating the aerosol effect to atmospheric residence time, a critical value in determining long-term effects. Measurements are also being made of the effects of stratospheric aerosols on the amplitude and phase of seasonally periodic variations in the amount of solar radiation received at NOAA's Mauna Loa Observatory, in Hawaii.

From this study, a climatology of nuclei is being developed by the Atmospheric Physics and Chemistry Laboratory with the eventual goal of providing atmospheric nuclei inventories at local, regional, and global scales. This information will permit an assessment of the contribution of human activities to the atmospheric nuclei budget. At the same time, investigators here are looking into the efficiency of nuclei-generating techniques used in weather modification projects, how well these nuclei succeed in glaciating clouds (that is, inducing supercooled water to freeze), and how long they remain suspended in the atmosphere. These studies are also covering the effect of the nucleating action of silver iodide on light quanta, water vapor, and atmospheric trace constituents.

THE EXPERIMENTAL METEOROLOGY LABORATORY has been concerned with investigating the physics and dynamics of convective clouds, from the scale of individual cumulus elements to the mesoscale systems influencing the southern Florida peninsula. Of particular interest is the interrelationship between cloud microphysics and dynamics and the processes which govern precipitation-formation within the clouds.

The laboratory has uniquely applied cloud-seeding technology toward reaching an improved understanding of cumulus precipitation processes, and how they are affected by deliberate modification. Confirmation during the 1960's that numerical models developed by the laboratory could predict seeding effects with reasonable accuracy led to field experiments in 1968 and 1970. Successes obtained then were followed by a quasi-operational project in the spring of 1971 to use weather modification techniques to mitigate Florida's severe drought. That project, conducted at the request of Florida Governor Reubin Askew, contributed an estimated five to ten percent of the April-May rainfall in the southern part of the state. Thus, combining the use of laboratory and numerical modeling the full-scale field experiments involving aircraft, radar, and ground measurements, the laboratory has attained a degree of understanding of how dynamic cloud seeding can affect the rain-making chain of events within individual cumuli.

Research into rainfall enhancement from cloud seeding has now progressed from a study of individual clouds to a more complex investigation into *mesoscale* effects from cloud mergers. A major effort to obtain the data needed to examine the relationship between seeding and precipitation on the mesoscale was carried out during the summer of 1973.

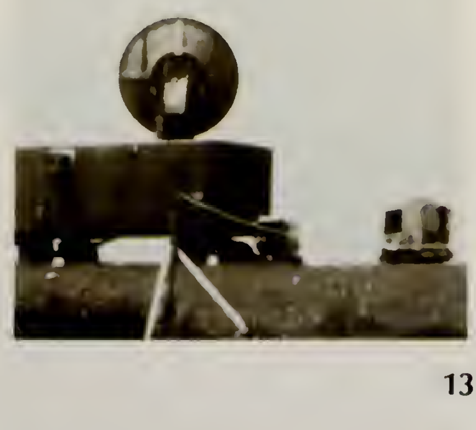
This field program included some ambitious cloud physics and cloud dynamics research designed to provide an insight into how cloud merging proceeds naturally and how it can be altered by the mass conversion of supercooled water to ice through seeding with silver iodide. Attempts were made to determine the effects of seeding on the aerosol budget of the atmosphere, the evolution of the hydrometeor water spectrum, the sub-mesoscale wind field, and the influx of heat and moisture at cloud base. Experimenters also measured the silver content of rainwater sampled from seeded and unseeded clouds to assess the ecological as well as the meteorological impact of cloud seeding.

As in previous years, the experiments used a randomizing procedure that makes it impossible for researchers to identify on which days clouds have been seeded until after the experiment. Clouds are selected for seeding, a seeding run is made, and the scientist presses his flare-release button — but only the person who arms or does not arm the flare racks, depending on his sealed instructions, knows whether seeding has actually occurred. In this way, even subconscious bias is kept out of research results.

With the advent of the mesoscale seeding program, Doppler radar analysis of the two-dimensional fields of motion of clouds in the research area assumed high importance. The dual Doppler techniques permit simultaneous measurements of rainfall amounts and winds, and divergence (the spreading out of descending air) can be calculated and monitored as storms build. The laboratory is also comparing satellite imagery brightness data with radar-determined cloud-top heights, in the hope of eventually learning to correlate the brightness measurements from satellites directly with precipitation, a scheme of great potential importance to such projects as GATE*.

In its efforts to simulate atmospheric processes, the Experimental Meteorology Laboratory has designed computer models of clouds and cloud groups of the type and scale selected for weather modification experiments. Thus far, these models have included a mesoscale dry sea breeze model of south Florida, now being verified, cumulus models used in planning field experiments, and the continuing development of a three-dimensional, time-dependent model of cumulus convection that shows great promise for the future. The evolution of art into science has been particularly evident as this laboratory has become a center of excellence for tropical and experimental meteorology. As field experiments have developed in recent years, and as increasing experience has been gained on the "practical" side of cumulus studies, the investigative field of view has steadily expanded — from cumulus clouds to the mergers of cumulus systems, and then to their role in the generation of severe weather and their effects on the heat, moisture, and vorticity budgets of the atmosphere.

Thus, what might at first glance seem to be primarily a weather-changing effort is actually a balanced, broad investigation of the atmosphere's basic weather factory, and its place in global scales of atmospheric chemistry and motion. It is also a persistent search for the cumulus-borne seeds of larger and more violent storms, and for clues to mitigating their destructive effects.



The Florida Area Cumulus Experiment had its third field season in 1973, observing the effects of cumulus cloud-seeding from aircraft and extensive surface instrumentation, including the University of Miami Doppler radar (one of a paired system) shown at right.

*The acronym for GARP (Global Atmospheric Research Program) Atlantic Tropical Experiment.

The Violent and the Great

As one laboratory explores the infant storms called cumuli, and the intricate patterns of development and decay which lead — or do not lead — to mature storm systems, other NOAA laboratories have concentrated on the most dangerous and destructive game in the atmosphereic compound — tornadoes and severe thunderstorms, hurricanes, and extratropical cyclones. The emphasis is scientific, or course, and the pursuit of knowledge is as systematic in these field-centered programs as in laboratory-locked ones. But, as the work attempts to ease the burden of destructive weather, it has an intensely human component as well.

Thunderstorms are the shortest-lived and smallest of these, and the most familiar. At their worst, they tower from a base only a few thousand feet above the surface into the lower levels of the stratosphere, and bring gale winds and inundating rains, hail and intense lightning, and the storm-within-a-storm — the tornado. Although familiar, these severe local storms are still filled with mysteries for the meteorologist and severe storm forecaster. One cannot simply fly an instrumented aircraft into an intense convective cell, or into a tornado, so that these storms have kept their privacy in a way hurricanes and extratropical cyclones have not. Research on these storms, then, seeks mainly to probe them deeply and systematically.

The National Severe Storms Laboratory, from its facility on the University of Oklahoma campus, conducts this investigation in NOAA, probing the spring skies over Oklahoma as the severe storm center-of-action makes its seasonal journey from the American southeast to the great plains. The spring program obtains storm measurements from a dense network of weather stations, an instrumented tower near Norman, serial releases of rawinsondes, conventional and Doppler weather radars, and instrumented aircraft. From this material, the laboratory works to improve present understanding of tornadoes, squall lines, thunderstorms, and related local storms, to develop methods for their early detection and identification — and improve present ability to predict their occurrence. The laboratory is also investigating how successfully — and beneficially — these severe events can be modified.

One important aspect of the Norman laboratory's program is the development of a comprehensive three-dimensional description — what amounts to maps of the varying, violent topography of these storms' turbulent interiors. And, gradually, the combination of data has begun to reveal this hidden terrain.

Several cases, for example, have shown similarly structured relationships between the principal updraft region, cold air outflow boundary, lowest surface pressure, and surface wind pattern. Although complicated variations are found from case to case, laboratory researchers now believe that surface winds respond dramatically to storm-generated pressure fields, although these pressure fields are not related to winds or to one another in the same way they would be at the larger scales of motion.

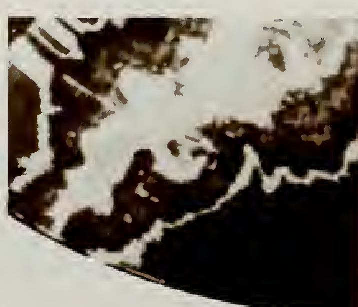
Scientists at the Oklahoma facility have also succeeded in detailing certain typical features of severe thunderstorms. Soundings obtained in and around such storms have confirmed the locations of major updrafts and downdrafts. Updrafts in the lower few kilometers typically produce a radar signature marked by weak echo partially surrounded by strong echo; however, not all weak echo regions are updrafts. Evidence now suggests that similar signatures aloft (between three and seven kilometers) may be caused by intrusions of dry air into the cloud near the precipitation-laden updraft. The proximity of dry air to rainy air aloft is known to encourage downdraft formation, as the dry air is chilled by evaporating rain and may descend violently to the surface, literally dragging other air to the surface. The dry-air mechanism, normally observed on the storm's southwest flank (which is exposed to the upper winds) is important in the movement of the "pseudo cold front" which horizontally separates the chilled air from the warm moist surface air feeding the updraft. Accelerations of this front are believed to be associated with tornado-producing, growing storm cells.

For the same reasons that severe thunderstorm cells cannot be probed by aircraft, they constitute a hazard to aviation, particularly where the thunderstorm is related to nearby turbulence. In a study partially funded by the Federal Aviation Administration, the Severe Storms Laboratory is studying the relationships between thunderstorm hazards and aircraft operations, with an eye to improving flight safety criteria near thunderstorms.

Such studies have shown that the location of a storm's gust front and the intensity of the maximum gust are closely related to storm velocity and intensity as revealed by radar echoes. Analysis of vertical profiles of different gust fronts is expected to define the height distribution of this relationship, and to help apply it to modified near-storm flight criteria.

Present emphasis is on determining the specific regions of wind shear in relation to turbulence. The horizontal wind in thunderstorms as seen by Doppler radar is scanned in real time for evidence of strong shear and variance. These areas are then sampled by instrumented aircraft to determine the turbulence distribution. During the 1973 spring program, Colorado State University's F-101 and an Air Force F-100 were used to probe areas of radar-indicated turbulence. The radar was the laboratory's 10-centimeter Doppler radar, combined with the Air Force Cambridge Research Laboratories' Plan-Shear Indicator, which provides a real-time wind-shear display on a standard radarscope.

The 10-centimeter pulsed Doppler radar system antenna at the National Severe Storms Laboratory has been paired with another, remote Doppler system. The type of return available to the severe storm researchers includes a conventional radarscope "hook echo" (below, left) and the vortex circulation marked by a closed "isodop." At right, a leased aircraft used in the Atmospheric Physics and Chemistry Laboratory's lightning suppression experiments.



Doppler radar development pervades the programs of the National Severe Storms Laboratory. This type of radar, which employs the principle of Doppler shift (returning echoes are changed in wavelength if the reflecting target is moving toward or away from the antenna) to monitor the three-dimensional processes within the stormcloud, is a uniquely useful tool for severe storm research. At the Norman laboratory, the Doppler radar project is coupling multiradar systems and new methods of recording and processing Doppler radar data. It is also trying to bring these methods to the point where real-time Doppler radar data would become available to forecasters in an easily interpreted format.

A single 10-centimeter pulsed Doppler radar (WDS-71) with excellent sensitivity and spatial resolution has been used for several years to scan severe storms. The nine-meter-diameter antenna is housed in a protective radome to ensure continued operation even under the worst weather conditions.

The WDS-71 samples and stores on magnetic tape Doppler data at selected angle and range locations. These digitally recorded data are processed in a general-purpose computer to provide a Doppler spectrum for each sample point within the storm. The spectra are further processed to provide researchers with high-resolution information on the distribution of reflectivity, an indicator of rainfall rate, and mean velocity and spectrum variance throughout the storm. The Doppler data acquisition is coordinated with standard meteorological observations from the laboratory's mesonetwork, aircraft measurements in the storm, and in-place photographic records obtained by NOAA scientists tracking the storm on the ground. Velocity fields displayed in the radar scan-plane indicate such significant dynamic features as tornado cyclones.

Because great computational effort is required to process Doppler spectra and because considerable meteorological information is contained in mean velocity and reflectivity values, effort has been expanded to develop on-line processors that can inexpensively provide estimates of these two parameters. A digital integrator and mean velocity processor, both developed at the Severe Storms Laboratory, provide these estimates, in real-time, for 200 range locations.

The mean velocity processor provides quantitative mean velocity estimates and displays these on a standard plan position indicator (PPI) radarscope. Consistent identification of mean velocity signatures associated with tornado cyclones may provide weather observers with more accurate information on the location and path of potentially damaging winds. Preliminary data taken simultaneously with the occurrence of a tornado suggests that a unique closed isotach may be the signature of vortex rotation. Laboratory investigators are trying to modify the display to enhance this type of signal.

As noted earlier, the 10-centimeter Doppler system was modified to use higher pulse-repetition rates, in order to measure tornadic speeds. These are believed to be lower than once thought, and the Doppler system is expected to provide a figure for them. Further modification involves decreasing the time required for accurate estimation of mean velocity so that the Doppler radar can scan at rates comparable to a conventional radar, or about 10 times faster than it does now.

A second remote Doppler radar located at Cimarron Airport, about 42 kilometers northwest of Norman, provides an opportunity to obtain greatly improved severe storm data. Data telemetered from the remote system is being combined with the WDS-71 data to provide real-time displays of vector velocity in the region common to the two radars. Techniques for reducing the range and velocity ambiguities associated with pulsed Doppler radars are the object of additional study.

Numerical, laboratory, and conceptual modeling of convection and related phenomena plays an important role in the Severe Storms Laboratory program. Convective processes leading to development of severe local storms are fully four dimensional, and involve the entire range of atmospheric phenomena, often in delicately unstable relationships. Although there is still too little information to simulate many smaller-scale processes, improvements in computer technology and increasingly informative observations are moving the models closer and closer to the actual processes.

Among the models under development is one showing dryline development and movement. The dryline, a quasi-discontinuity in the near-surface moisure field, is one of the incompletely understood factors which control the evolution of severe storms in a relatively "quiet" environment. Additional research into interactions between the storm and its environment includes analysis of severe storm updrafts and interactions with air below the cloud.

Scientists from the Oklahoma laboratory are also attempting to improve their understanding of intense vortices in the atmosphere by direct observations of tornadoes and by close-in observations of a milder whirlwind, the Florida Keys waterspout. These data are in turn used in numerical models of vortices. The waterspout work is providing the first comprehensive survey of the characteristics and incidence of these interesting phenomena.

A major objective of the laboratory is to improve techniques used for detecting, indentifying, and tracking the hazardous weather events associated with severe thunderstorms. This work stresses improved acquisition of key weather elements for use in numerical models and predictive systems, and better ways to distill detailed observations of hailfall, high rainfall rates, and strong winds on the scale of individual thunderstorms from weather radar echoes.

TWO PROJECTS CONDUCTED BY THE Atmospheric Physics and Chemistry Laboratory address two of the destructive by-products of severe mesoscale storms — hail and lightning. Hail research has been conducted within the National Hail Research Experiment, or NHRE, which is being carried out in northeastern Colorado under the direction of the National Center for Atmospheric Research. Planned as a five-year experiment for the 1970's, NHRE had its third field season in 1973, which was also its first year with randomized seeding.

NOAA support has included installation and operation of a 450-station hail and rain gage network to measure the effectiveness of the cloud treatment and for purposes of storm analysis, operation of two meteorologically instrumented aircraft (13 aircraft are involved in the

total NHRE flight research program), and contributing to the scientific direction of the daily field research effort. In 1973, this support included operation of a dual-Doppler 3-centimeter radar system, which provided velocity field mapping of the particle and air motions within storms. But the level of participation by the Environmental Research Laboratories has dropped sharply. Operation of the surface precipitation network has been transferred to NHRE, NOAA aircraft have not participated since 1972, and Atmospheric Physics and Chemistry Laboratory scientists no longer direct field research operations.

The lightning-related projects of the laboratory are concerned with two sides of the thunderbolt — possible inhibition of the charge process which produces lightning, and instrumentation capable of monitoring electric field levels and lightning discharges over a given surface area. Modification of the thunderstorm's electrical structure by seeding with metallized chaff appears to be one promising method of mitigating the effects of destructive lightning discharges. This technique increases the conductivity of the normally insulating air, causing the electrical charge to bleed off at a small fraction of the levels required to produce a lightning stroke. Such techniques would be beneficial in preventing uncontrollable lightning-ignited forest fires and protecting against lightning hazards in sensitive areas at critical times — for example, at underground nuclear test sites during experiments.

Promising results have been obtained from summer field experiments in Colorado, where chaff seeding has markedly reduced the electric field beneath the thunderstorm cloud base. As the project evolves, chaff seeding of the charge center *within* the thunderstorm cloud will be attempted, to evaluate whether, and how well, the technique can be used to suppress lightning.

The laboratory has also developed an elaborate lightning warning system in cooperation with the National Aeronautics and Space Administration's Kennedy Space Center. The device provides continuous assessment of the lightning hazard in the Center's launch areas. The new system integrates weather radar, an electric field mapping network, and a lightning position plotter; a continuous cathode ray screen display shows areas of precipitation, electric field contours at the ground, and the positions of lightning discharges during preceding 10-minute intervals. The electric field contours trace the development and movement of electrically active clouds near the Space Center area before and during the occurrence of lightning discharges.

Hurricanes combine violence and duration uniquely. They can attack a coastal sector involving thousands of square miles, control the lower atmosphere over synoptically large areas, and whip people and communities in their path with a deadly combination of high winds, heavy rains, and storm tides. For scientists concerned with weather modification there is no more exacting quarry than these violent tropical cyclones. And there are urgent reasons for "hunting" and taming them. Although improved techniques of hurricane detection and timely warning have greatly reduced the number of deaths caused by hurricanes in the United States, they have not been able to halt the rising loss of property. The average annual cost (before 1972) of hurricane damage was about $450 million. In 1972, one of the mildest Atlantic hurricane seasons of record, hurricane Agnes and the torrential rains and widespread flooding which accompanied the storm, caused an estimated $3 billion damage in the Atlantic tier of states. Clearly, any weather modification techniques which could mitigate such destruction would be of great general benefit.

The National Hurricane Research Laboratory has been subjecting these huge water-logged heat engines to intensive scrutiny, and has studied in field experiments the possibilities of certain hurricane-changing methods. This effort typically attempts to inhibit or unbalance some critical aspect of the way a hurricane receives, organizes, and distributes its enormous energy.

Most hurricane modification research has centered on the alteration of processes governing the rate of release of latent heat from condensing and freezing water vapor in the storm, in areas of highly organized convective-scale motion. Project Stormfury, a cooperative undertaking of NOAA, the U.S. Navy and U.S. Air Force, has made an effort each year from the early 1960's through 1972 to meet and modify hurricanes over the tropical Atlantic and Caribbean. The objective here has been to demonstrate that the peak winds of a hurricane can be diminished significantly by seeding the latent cumulus towers just outside the eyewall with silver iodide smoke. This stimulates the growth of the towers, robbing energy from the original eyewall and creating a secondary eyewall. The resulting displacement of the eyewall outward to a new and larger radius reduces the degree of organization of the storm, spreading the storm's energy and weakening the hurricane.

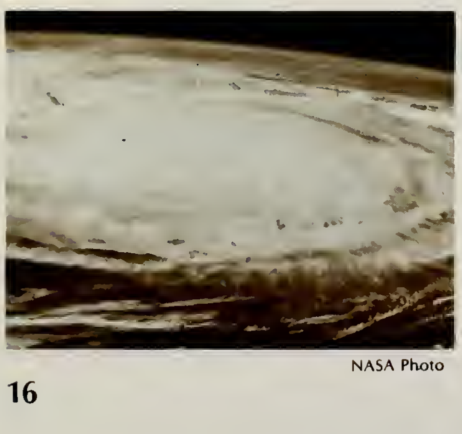
It is not an easy task. Besides the obvious problems of attempting to see — and control — something of the size and violence of a hurricane from something as small as an aircraft, there are the difficulties of being able to read the hurricane's responses to seeding — the natural "noise level" of change tends to mask any small-scale changes produced by seeding. And there has been a lack of experimental opportunity.

The Stormfury eligibility rule, even as liberalized in 1970, excludes from seeding storms predicted to come closer than 50 miles to a land area within 18 hours after seeding. Under these and the more restrictive criteria previously applied, Stormfury scientists have had only four opportunities in more than a decade of tries: Esther in September 1961, Beulah in August 1963, Debbie in August 1969, and Ginger in September 1971.

Although the sample is small, the experiments have produced some interesting and encouraging results. The seeded portion of Esther's eyewall faded from the radarscope, indicating either a change of liquid water to ice crystals or the replacement of large droplets by smaller ones. On the second day's seeding, nothing happened; however, subsequent analysis showed that the seeding material had missed the cloud.

On the first day of seeding Beulah, the seeding material apparently did not enter the appropriate clouds until after the monitoring aircraft had left the scene, and no results were measured. But on the second day, Beulah's central pressure increased soon after silver iodide seeding and the area of maximum winds moved away from the storm center.

Debbie, the first subjected to multiple seedings, was seeded at two-hour intervals for five seedings on each of two days (August 18 and 20, 1969), with massive doses of silver iodide. These seedings appeared to have a significant effect on maximum wind speed and some structural features of the storm.



NASA Photo

Atlantic hurricane Ellen (1973), shown here in a view from Skylab, was probed by NOAA scientists and aircraft to explore the hurricane cold wake phenomenon — the cold water which appears to upwell behind some storms. Airborne bathythermographs were dropped behind Ellen to profile water temperatures. On facing page, a hurricane model shows the three-dimensional flow of particles through a hurricane.

Ginger moved into an eligible area, and rainband clouds far removed from the center of the storm were seeded twice on September 26 and four times on September 28. But the clouds did not have much seedability — the combination of vertical temperature and humidity distributions that provides the potential buoyancy which seeding unlocks — did not contain much supercooled water, and were in a hurricane wind field already relatively weak and dispersed. This seeding produced no identifiable changes in the hurricane beyond some small-scale effects in the seeded clouds themselves.

Thus, some promising results appear against a background of very little experimental opportunity. In 1973, NOAA acted to change this feature of the project, suspending Stormfury until new research aircraft and airborne instrumentation systems arrived, and laying plans for Stormfury operations in the Pacific later in the decade. There the number of typhoons eligible for seeding is expected to be about three times greater than the number of eligible Atlantic hurricanes.

In the meantime, the laboratory sharpens its skills. Hurricane research (as distinguished from hurricane modification) flights continue as storms come within reach of the Miami-based aircraft and scientists. In particular, new cloud physics instruments available to hurricane researchers are permitting a much improved examination of the microphysical processes in maritime cumulus clusters. This information is needed to define the seedability of such clouds as they occur in hurricanes. Research work is also attempting to define water and energy budgets at hurricane scales of time and motion.

Numerical modeling has continued to make rapid progress at the laboratory, as improved data collection techniques have brought vastly improved cumulus characterization to the models, and such innovations as a nested grid system — in effect, a hurricane-scale model within a larger-scale one. Even with the symmetric models — simulations which are "smoother" than the natural atmosphere — researchers have been able to obtain increasingly realistic simulations of hurricane modification experiments. The laboratory is also working on a real-data hurricane model for operational prediction, in a cooperative effort with the National Meteorological Center of NOAA's National Weather Service.

Computer model runs give clear indications that the relatively small amounts of sensible heat and moisture the hurricane picks up from the underlying ocean surfaces are critical to the development of intense storms. Data gathered by research aircraft show that water vapor transport is the more important of the two processes, and model runs which eliminate this transfer result in very significant weakening of the model storms.

In an effort to exploit this fact, the National Hurricane Research Laboratory has had a research contract with the Illinois Institute of Technology Research Institute to develop monomolecular film which will suppress evaporation and have strong enough bonding laterally so that it would not disintegrate in rough seas. A film consisting of linoleic acid, polyvinyl alcohol, and derivatives of polyvinyl acetate was engineered for this purpose. In sea trials, one-mile-square slicks were spread quite readily. Further, it was determined that, at frequencies greater than 0.29 Hertz, wave energy within the slick was only 54 percent of that outside — that is, the short capillary waves were damped significantly. However, the film appeared to break up quickly under the stress of moderate wind and wave action. (This work is being continued by the Sea-Air Interaction Laboratory of the Miami-based Atlantic Oceanographic and Meteorological Laboratories.)

The other facet, the transfer of sensible heat, is now being examined in a new light — the effect of hurricane winds on sea-surface temperatures and how these changes affect heat transfer. Some hurricanes have been known to leave a cold wake and this wake has been well documented by oceanographic research vessels. It is obvious that the hurricane circulation deepens the ocean mixed layer and accounts for some decrease in surface water temperatures by this means. But both numerical models and measurements made in hurricane Ginger (1971) suggest that divergence of surface waters near the core of the hurricane may lead to upwelling of such a magnitude that the thermocline may be destroyed and quite cool water may be forced to the surface. The area subjected to this effect may be limited in size to the immediate vicinity of the hurricane but the effect may be of sufficient magnitude to reverse the normal flow of sensible heat. An extensive program by the National Hurricane Research Laboratory to determine this effect using airborne expendable bathythermographs was begun during the 1973 season.

It was once thought that the climatology of the southern North Atlantic ocean was well understood; the trades, the inversion due to the tropical anticyclone, waves in the easterlies, and the intertropical convergence zone seemed to tell most of the story. Then, in the middle 1960's, chemists discovered that air arriving at Barbados (in the summertime) was frequently laden with dust of Saharan origin. Since then investigation by the National Hurricane Research Laboratory has shown that pulses of Saharan air travel across the Atlantic following African perturbations, in a duct from 5,000 to 15,000 feet. Besides the telltale dust, these pulses have their own distinctive temperature signature. This huge lens of warm air, 1,000 miles or more across, blocks cumulus convection and so is of great importance to weather in its vicinity.

Research continues on the Saharan Air Layer (SAL) and its effects on weather events in the Atlantic. The nature and energetics of the African disturbances themselves are also under study to determine their origin and why, in so many instances, they travel so far before they find an environment favorable to their development into tropical storms and hurricanes.

EXTRATOPICAL CYCLONES ARE the largest heavy-weather systems in the atmosphere, and probably the most damaging — not much destructive weather occurs over the continent that is not linked to one of these atmospheric giants. They are also the most familiar to most Americans, for, as they dominate continental weather, they also dominate the weather maps, great centers of low pressure from which warm, cold, and occluded fronts run out like tentacles, bearing heavy snows in one quadrant, flooding rains in another, severe thunderstorms and tornadoes in a third. So pervasive are these great cyclonic systems that they seem to *be* the weather, rather than just a part of it. It is natural, then, for scientists who have altered the component systems to look to extratropical cyclones as fair game for weather modification.

In the Atmospheric Physics and Chemistry Laboratory, experience had been gained in several seasons of modifying Great Lakes winter storms, and much effort had been invested toward developing a chemical and physical backdrop for possible modification of weather over the Great Plains. By the 1970's weather modification had entered an era of physical experimentation refined by statistical and numerical methods, and scientists had developed a systematic, if rudimentary, understanding of a wide range of weather-changing causes and effects. At the same time, novel seeding methods had become available that permitted massive, large-scale treatment of cloud systems, and the ability to monitor the development and modification effects in such large systems had arrived in the form of high-resolution visible and infrared radiometry from new generations of environmental satellites.

Thus, in 1973, sensing that time and technology were right for the modification of extratropical weather systems and their severe effects, the laboratory planned investigations of the effect of artificially introduced perturbations at the mesoscale level upon both cyclonic and severe local storm weather systems. Much of the initial effort has been to develop a numerical model capable of simulating interactions between cyclone and mesoscale systems, and a search for the vulnerabilities of these great storms.

Winged Laboratories

Any scientific effort to observe atmospheric events has always reached a point where the atmosphere itself must be sounded, its properties measured as they vary with altitude. The daring balloon ascents of early meteorologists, instrumented box kites, the sounding balloons in use today, and the scanning and sounding sensors aboard earth-orbiting satellites — all flow from this effort to add a vertical dimension to weather observation.

Aircraft have played their part in the global, day-to-day routines of meteorological data collection and do today — much of the world's weather is scouted by aircraft from the U.S. Air Force Weather Service. But, increasingly, airplanes have come to be platforms from which to examine weather systems where they occur, and to modify them. The aircraft have become themselves laboratories, crowded with the traditional and startlingly new instruments of today's experimental meteorology.

NOAA's Miami-based Research Flight Facility provides such aircraft and a cadre of uniquely experienced crews. With origins going back to the research aircraft operated by the former Weather Bureau in the early post World War II years, the Research Flight Facility has done what most airmen would call everything — thousands of sorties into hurricanes, winter storms, tropical cumuli, the Indian monsoon circulation. From these hours-long ordeals by wind and water, scientists have gathered much of the precise information that exists on the events probed by these aircraft, and how to change them. It is a singular way for pilots and flight meteorologists and navigators and instrument and aircraft technicians to make a living, something between barnstorming and scientific inquiry, between running a laboratory and a small non-sked air line.

The Research Flight Facility operates two aircraft, a WC-130 *Hercules* and a DC-6. Both airplanes are four-engined, long-range aircraft capable of carrying out a wide variety of environmental research assignments, anywhere in the world.

Both the DC-6 and C-130 contain a basic instrumentation system for the airborne measurement of temperature, humidity, pressure, winds, position, and related parameters, and both can be specially fitted to obtain measurements of specific phenomena of interest to scientists from NOAA laboratories and other organizations. The C-130, a fast-climbing airplane which operates most efficiently at the 25,000 to 30,000-foot level — the level of most interest to cloud physicists — is equipped with a wide variety of cloud physics instrumentation for the detection and sampling of the in-cloud environment. Included are an infrared air temperature radiometer, ice-nuclei counter, aerosol detector, liquid water content devices, and hydrometeor foil sampler. In 1974, this aircraft is being modified to accommodate the Airborne Weather Reconnaissance System (AWRS, or "Ay-whars") an advanced airborne meteorological data system developed by the Air Weather Service, to be used in GATE.

The piston-engined DC-6 is better suited to operations in the low-to-middle levels of the troposphere. Among other instrumentation, it carries a turbulence system assembled and installed in 1970 by the Research Flight Facility and the Boundary Layer Dynamics Group.

The Research Flight Facility C-130 "four-one Charlie" (below) and the DC-6 will eventually be joined by new Lockheed WP-3D aircraft (at right), specially modified and instrumented to perform NOAA's unique airborne research mission.

This gustprobe system measures the parameters necessary to determine the aircraft's motion with respect both to the ground and to the air through which it is flying. The end product is a calculation of how much heat and moisture is being added to or subtracted from a cloud probed by the airplane, a very important consideration in understanding cloud structure and dynamics.

Both aircraft have been widely used in NOAA's weather modification projects. THE C-130 carries eight seeding racks, four on each side of the fuselage, containing a total of 416 silver-iodide flares. A pushbutton firing mechanism located at the visiting-scientist station on the flight deck and connected to an electrical sequencer is used to ignite and launch the flares during cloud penetrations. The DC-6 can carry two racks mounted in pods suspended below each wing tip, giving this airplane a seeding capability of 208 flares.

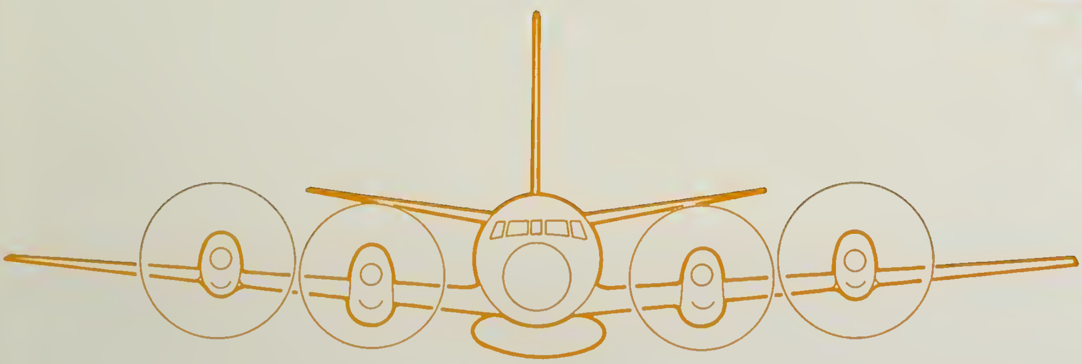
The way the aircraft are used means a wide range of missions in any given year. On average, the two Research Flight Facility airplanes log a total of about one thousand flight hours per year, divided among NOAA's laboratories and other organizations. For example, "41-Charlie," the C-130, logged 478 hours 45 minutes during fiscal year 1972, broken down as follows: Project Stormfury, 63 hours; hurricane research, 65 hours 50 minutes; Naval Research Laboratory projects, 142 hours 30 minutes; laser profilometer research, 20 hours 20 minutes; fisheries research, 19 hours 15 minutes; National Center for Atmospheric Research projects, 2 hours 15 minutes; NASA projects, 27 hours 5 minutes; hail project support, 71 hours 55 minutes; calibration and proficiency, 66 hours 35 minutes. The DC-6's season was similarly varied.

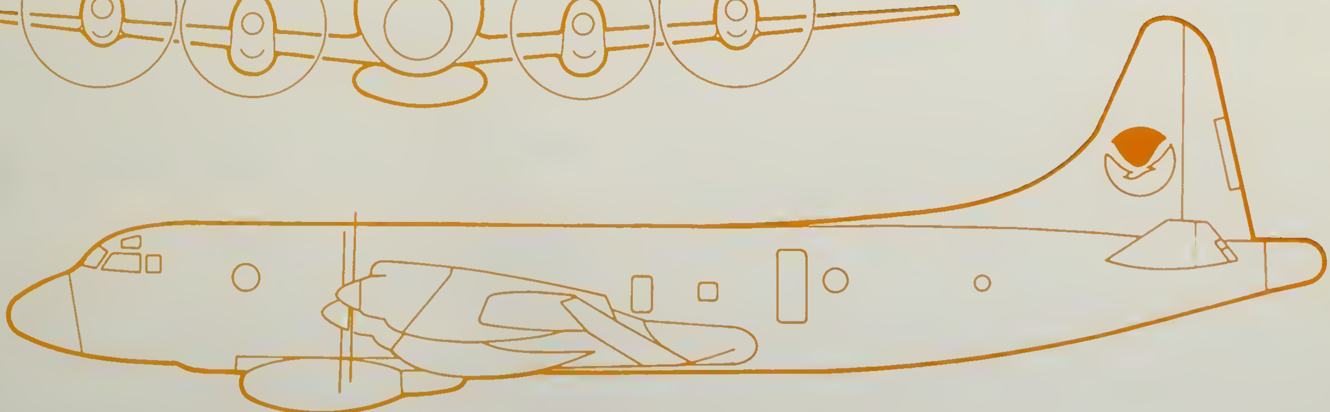
Time has been kind to the older airplanes used by the NOAA 'research squadron, mainly because of a rigorous maintenance and updating program. Still, time passes, so that in recent years there has been a continuing phase-out of the older aircraft in favor of new turbine-powered ones.

Two efforts conducted in the Weather Modification Office are concerned with delivering the advanced instrumentation systems these winged laboratories must have, and develop new techniques to measure processes in the atmospheric boundary layer. The Instrumentation Task Force is concerned with acquiring or developing modern scientific airborne research instrumentation for Research Flight Facility aircraft. Its immediate goals are to prepare the DC-6 for the GATE project by updating the gust probe and flight level sensor data recording system; procure and install one Airborne Weather Reconnaissance System (AWRS) for the NOAA C-130 for GATE; procure two new, four-engine, long-range research aircraft; and install on these aircraft a Research Aircraft Meteorological System (RAMS), a NOAA-developed data unit tailored to the special needs of experimental meteorology.

The Boundary Layer Dynamics Group studies the atmospheric boundary layer, its microstructure and turbulence, using mainly airborne techniques. Emphasis here is on atmospheric dynamics, particularly the interaction of turbulent exchange characteristics with the mean flow. In this connection, evaporation measurements were made during BOMEX, and, during IFYGL, aspects of air-lake interaction were determined to establish the evaporation cycle and the nature of lake storms.

As the program for the modification of extratropical storms matures, this group will play an increasingly important role in obtaining *in-situ* measurements — for example, the fluxes of heat, momentum, and water vapor, using remote sensing devices — for use in the mesoscale models which are expected to become available late in the decade of the 1970's.





The Inadvertent Hand of Man

As there are programs to see what can be done to atmospheric processes deliberately, there are also programs which seek to measure what mankind has been doing to these processes inadvertently for centuries. The Air Resources Laboratories, often under contract to other Federal agencies, deal in the peculiar meteorologies associated with urban air quality, atomic tests and reactor siting, the environment generally, and the poorly understood long-term effects of human activities on global weather and climate.

The concern here is with atmospheric processes at all levels and scales, the chemistry and motion of atmospheric constituents, and the development of new methods of measuring and interpreting these processes and events. If there is a single goal shared by these efforts, it is to remove the term "inadvertent" from such cultural effects. The search is for data which permit us to identify what the actual effects of our activities have been, and to predict what the atmospheric and climatic consequences of our future actions will be.

Monitoring the Global Atmosphere

That the atmosphere is being contaminated with gases and suspended solids is generally accepted; but the absence of quantitative data on the dynamics of the problem has made the urgency of this impossible to assess and has led to widely differing speculations — for example, that the polar ice caps will be melted because of a heat buildup beneath the atmosphere's "greenhouse" of increasing atmospheric carbon dioxide; or, alternatively, the screening out of solar radiation by particulates in the atmosphere will produce another ice age.

The purpose of the Air Resources Laboratories' geophysical monitoring program for climatic change is to provide quantitative data of this type, measured as precisely as technology permits. It also seeks to sample adequately the "clean" air of polar and tropical land and ocean environments, in order to provide a baseline from which to determine global trends in contaminants. These data take the form of dependable measurements of presently existing amounts of natural and man-made contaminants in the atmosphere, determination of the rates of change of these amounts, and measurements of those atmospheric properties which are affected by contaminants. This NOAA program is carried out in close cooperation with other agencies, universities, and other groups in the United States, and with the global monitoring activities of the United Nations' World Meteorological Organization.

Mauna Loa Observatory, on the big island of Hawaii, is the oldest baseline station in operation. It's location at 3,400 meters' altitude on the flank of the Hawaiian volcano makes the observatory an ideal geophysical benchmark station. It is remote from pollution sources, there is neither dense population nor heavy industry nearby, and it is isolated from the planetary boundary layer of low-level air by the tradewind inversion during most of the year and by the subsidence of air from aloft caused by differential nighttime cooling of the mountain slope.

Observational programs there measure meteorological elements, solar radiation, atmospheric carbon dioxide, ozone, turbidity, and aerosols. Several other agencies operate measurement programs at Mauna Loa. These include, for example, high-volume particulate sampling for analysis of beta- and gamma-emitting particulates (Atomic Energy Commission), high-volume particulate sampling for total aerosol mass (Environmental Protection Agency), gas sampling for sulphur dioxide and oxides of nitrogen analysis (Environmental Protection Agency), a solar coronometer to measure light scattered by electrons in the solar corona (National Center for Atmospheric Research), and gas sampling for tritium in the form of HT, "heavier" hydrogen, and HTO (University of Miami for the Atomic Energy Commission). Of special importance is the cooperative effort with the National Center for Atmospheric Research to operate their advanced gas-sampling system. This measurement program covers sulphur dioxide (SO_2), nitrogen oxides (NO_x), ammonia (NH_3), freons, and other gases, and adds much new data to the baseline monitoring.

Research at Mauna Loa is directed mainly toward improving the observational tools and techniques used by the facility. Investigations are under way, for example, of the detectability of background concentrations of sulphur oxides, carbon monoxide, nitrogen oxides, and other gases; the horizontal and vertical distributions of aerosols; methods of assessing global distribution of anthropogenic and natural pollutant-sources; and the feasibility of monitoring other properties of atmospheric constituents — for example, the chemical composition of bulk and individual aerosol particles.

Lidar (from light detection and ranging) soundings are being made from the facility to provide profiles of aerosol populations and distinguishing the tropospheric and stratospheric inventories. The lidar system, capable of measuring the vertical distribution of particulate matter from about 200 meters above the ground up to 30 kilometers above sea level, was designed for the Air Resources Laboratories by NOAA's Atmospheric Physics and Chemistry Laboratory. Advanced lidar systems are being designed to provide additional data on aerosol characteristics. Cloud condensation and freezing nuclei monitoring supplement the observatory's Aitken monitoring programs.

Although much of the geophysical monitoring program is new, scientists have been able to make some conclusions based on earlier Mauna Loa

The oldest baseline station in operation, Mauna Loa Observatory provides an almost pristine environment for the systematic measurement of the small atmospheric changes that signal trends in climatic change.

observations. Atmospheric carbon dioxide data since 1956 show that global levels are increasing at an average of 0.7 part per million per year. This rate is not constant, but varies with time for reasons not yet understood. A similar long-term trend in atmospheric turbidity caused by anthropogenic particulate loading has not been discernible from solar radiation measurements. A study by the Atmospheric Physics and Chemistry Laboratory, using Mauna Loa and shipboard data, indicates that there has been a noticeable increase in the concentration of aerosol particles in the lower levels of the atmosphere over the North Atlantic, but not in other ocean areas. Short-term changes in atmospheric opacity, however, are associated with world-wide volcanic eruptions when the volcanic material reaches stratospheric heights. During periods of little or no volcanic activity, the solar radiation received by the earth undergoes annual cycles in which atmospheric transmission is lower during the summer months. The monthly averages of Aitken nuclei concentration at Mauna Loa correlate with local volcanic activity, and an "island effect" has been identified in the diurnal variations of Aitken and freezing nuclei concentrations.

Antarctic observations are made cooperatively by NOAA and the National Science Foundation at the South Pole station. Solar radiation, turbidity, ozone, carbon dioxide, carbon-14, and radioactivity are monitored, and standard surface and upper-air data are obtained.

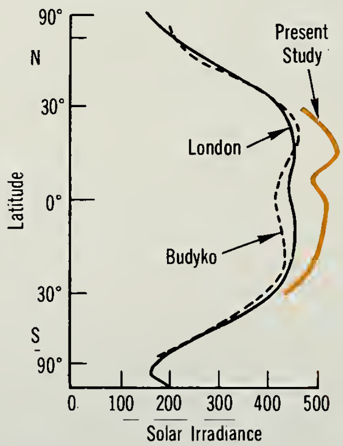
The Antarctic carbon dioxide data augment and confirm the gradual increase of this gas noted earlier. The reduction in solar radiation by stratospheric volcanic dust from the Mt. Agung eruption was observed here even more strongly than at Mauna Loa. Expansion of measurements at this site is very important to provide more polar data on contaminants. As a first step a multi-channel solar radiation system identical to that at Mauna Loa and continuous carbon dioxide measurements were installed in late 1973.

The first steps to model regional dilution of pollutants have also been taken. Beyond the first hundred miles or so, air trajectories are used to describe the horizontal dispersion, particularly for long-term pollutant releases. These trajectories can be routinely prepared via computer analysis of wind observations in and above the planetary boundary layer across the United States. The continuation of the pollutant travel across Europe and Asia is treated by using climatological airflow patterns at about 1,500 meters above the ground; the lateral dispersion around an average trajectory includes both the meander of individual trajectories and the spread around each individual path. Vertical dispersion is treated as a vertical eddy diffusion process.

The global model is being used in several ways. First, a global pattern of a radionuclide, Krypton-85, a product of the nuclear industry with a 10.7-year half life, has been predicted. The model calculations (including regional dispersion) permit the estimate of the population-dose to the world for a given release of Krypton-85.

Efforts to improve the models by using new tracers of opportunity are also under way. Thus, a collaborative program with the National Bureau of Standards supported by the Department of Defense Advanced Research Projects Agency is attempting to improve on the vertical mixing intensities in the troposphere by using cosmogenic Argon-37.

Freon-11 is an inert gas released to the atmosphere from aerosol propellant cans, and Air Resources Laboratories scientists have demonstrated that concentrations in the atmosphere of the order of parts in 100 billion can be easily measured with electron-capture gas chromatography, and that the Freon-11 is dispersed globally. Plans for a collaborative monitoring program with the Atomic Energy Commission to map the three-dimensional global distribution of this gas are under way. From this information and the source strength of Freon-11 which has been supplied from commercial firms, it will be possible to infer the rate of transfer of this inert substance between various atmospheric compartments.



The Air Resources Laboratories are actively planning new observations to enhance Arctic and Southern Hemisphere coverage. Working with the Navy's Arctic Research Program Office, an observatory has been constructed at Point Barrow, Alaska, that measures carbon dioxide, ozone, and turbidity. Automated equipment has been progressively installed including multichannel radiometers, Aitken nuclei counter, and Dobson spectrophotometer. A cooperative solar radiation study with the Smithsonian Radiation Biology Laboratory is also conducted here with NOAA operating the Smithsonian's radiometer systems in parallel with its own for an enlarged, mutually beneficial, effort.

A plan coordinated with scientists beginning to plan the national programs of New Zealand and Australia seeks to provide a background monitoring station in the less-industrialized world south of the equator. The National Geographic Society, at the laboratories' request, made an initial assessment of possible South Pacific island locations for an observatory.

A location at Cape Matatula, Tutuila Island, in American Samoa was selected and, with the assistance and support of the Samoan population and the government of American Samoa, an initial sampling program was begun in June 1973. Measurements include turbidity, ozone, carbon dioxide flask sampling, Aitken nuclei, collection of precipitation for chemical analysis, and operation of a National Center for Atmospheric Research gas-sampling system identical to the one at Mauna Loa.

To complete the NOAA plan for baseline measurements, two additional observatories are planned, one on the

west coast of the United States at a location which is now relatively free of local pollution. Questions of future land use, climate, and logistic feasibility are being studied and preliminary sampling programs have begun to select the best location.

Finally, a location is needed to compare trace contaminant levels representative of "clean" Atlantic air with flow from the United States. The one location that seems to meet this objective is Bermuda. A cooperative effort with the University of Rhode Island has begun to obtain data (carbon dioxide, Aitken nuclei, precipitation constituents) which will indicate whether formal negotiations for an observatory should be initiated.

Global scale modeling of the transport of atmospheric contaminants is an expanding program of the Air Resources Laboratories. The domain extends from pole to pole and from the ground to 40 kilometers with a 2-kilometer vertical and 20-degree latitude grid-spacing in the two-dimensional model. The exchange coefficients vary with altitude, latitude, and season. Slantwise mixing in the lower stratosphere deduced from bomb debris tracers mixes primarily from higher altitudes near the equator to lower altitudes toward the poles. The model runs by iteration with a one-day time step. Inputs can be accommodated according to any time or space schedule.

The Air Resources Laboratories are planning long-range atmospheric tracer experiments to study transport and diffusion of gaseous plumes over continental distances. These experiments will be used to extend our understanding of the behavior of pollutant plumes to regional and continental scales and improve our ability to relate the location and strength of pollutant sources to distant air concentration measurements. The ideal tracer would be a non-toxic gas that undergoes no reaction in the atmosphere, is not removed by precipitation, does not decompose or plate-out, can be detected in minute concentrations, and has virtually no existing background in the atmosphere.

Two main alternatives have been considered. The first involves development of new tracers and techniques for continental-scale experiments. Potential long-range tracers include sulphur hexafluoride (SF_6) and two fluorocarbons.* All are detectable by electron-capture gas chromatography at extremely low concentrations. The use of sulphur hexafluoride as a long-range tracer appears impractical because of the high average background concentrations already in the atmosphere (on the order of one part in 10 trillion) and likely interference from many strong local sources. However, sulphur hexafluoride is still an excellent tracer for distances up to several hundred kilometers.

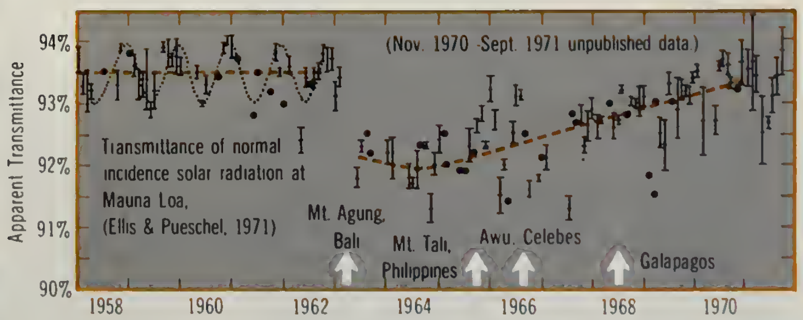
A field experiment was conducted in 1972 to test equipment and techniques for release, sampling, and analysis of the fluorocarbon tracers and to obtain plume data to a distance of 90 kilometers. These tracers, along with sulphur hexafluoride, Krypton-85, methyl iodide, and uranine dye were released from a 76-meter stack over a three-hour period. Measurement of sulphur hexafluoride, and both flurorocarbons were made with a chromatograph designed for this project. The limits of detection with this instrument were about five parts in 10 trillion (by volume) for sulphur hexafluoride, one part per trillion for 12B2, and three parts per trillion for 114B2. Detection limits can be lowered by preconcentration of the sample. A simple cryogenic technique for field concentration of samples was successfully demonstrated and concentration factors up to about 40 were achieved.

The second alternative is to take advantage of a source of opportunity — the Krypton-85 emitted from a nuclear fuel reprocessing plant — to obtain long-range plume data. Drawbacks are the high cost of Krypton-85 sampling and analysis, which limits the number of samples that can be processed, and the high probability that the plume would be lost in the general background levels of Krypton-85 at the extreme ranges (thousands of kilometers) of interest to this study.

These drawbacks are outweighed by the availability of a continuous Krypton-85 plume emanating from the National Reactor Testing Station in Idaho. This will allow routine sampling over a period of months which is preferable to restricting the experiment to relatively few selected meteorological conditions. Calculations indicate that detection of this plume is feasible to distances of at least 1,500 kilometers.

A tracer experiment has been run using this plume, with cryogenic sampling equipment installed at 10 to 15 National Weather Service stations along an arc from Minnesota to Texas, about 1,500 kilometers from the source and samples collected twice daily over a four-month period. At this distance (about three days' travel) the plume goes through diurnal cycles of wind and stability conditions and also shows the effects of passage over mountainous terrain. In analyzing experimental results, sample concentrations are being related to source strength, meteorological trajectories, wind speed, and stability. Results are also being used to develop a model of plume transport and diffusion to a distance of several thousand kilometers. An important tool developed for this analysis is a computer trajectory program that calculates trajectories of air parcels either forward or backward in time on a synoptic scale using observed winds. Trajectories can be computed at a single level or for a layer of any thickness above an averaged terrain. In the latter case, the observed winds are averaged through the thickness of the layer. Trajectories can originate from any point four or more times daily, and can be of any duration up to ten days.

Some climate-monitoring tools of the trade, and some early results. From left, sun-following pyrheliometers, spore trap, pyranometer, trap-sampler (for sulphur, nitrous oxides, and aerosol mass), and Dobson spectrophotometer. At far left, apparent trends in solar irradiance from pole to pole; at right, transmittance and the effect of volcanic eruptions.



*12B2 (CF_2Br_2) and 114B2 ($C_2F_4Br_2$).

The Meteorology of Pollution

Much of the Environmental Protection Agency's research and development work in the atmospheric sciences is carried out by the Meteorology Laboratory, which acts as the agency's focus in air pollution meteorology for both research programs and operational support activities. The laboratory is staffed by Air Resources Laboratories meteorologists on assignment through a continuing (since 1955) interagency agreement with the Environmental Protection Agency. The Meteorology Laboratory is located at the Environmental Protection Agency's National Environmental Research Center, Research Triangle Park (near Raleigh, Durham, and Chapel Hill), North Carolina.

The laboratory's research program has focused on the development of a hierarchy of general urban-regional diffusion models, assessment of new empirical and numerical modeling techniques, and validation of newly developed urban diffusion models. There is also a strong effort in remote sensing here, aimed at developing instruments capable of measuring mixing depth, temperature profiles, and relative aerosol concentrations in the planetary boundary layer.

Several unique devices have been delivered by this program. One is a truck-mounted, mobile lidar system capable of measuring the three-dimensional atmospheric aerosol structure, mixing depth, and stability. The Thermasonde is a radiometric temperature sensor system that provides information on the vertical temperature profile of the atmosphere to an altitude of 1,500 meters. The instrument passively senses naturally occurring microwave energy (produced by the permanent magnetic moment of oxygen molecules in the atmosphere) which can be expressed as air temperature. This device also provides information on mixing depth and atmospheric stability, meteorological elements used in diffusion models and air pollution potential forecasting.

The sunphotometer is a simple, compact instrument that measures the atmospheric turbidity coefficient (loss of light due to scattering and absorption of aerosols and gases in an atmospheric column between the instrument and the sun) at 380- and 500-millimeter wavelengths. It has been used in a global network of stations to determine worldwide background and trends in turbidity as a basis of studies of long-term global pollution trends.

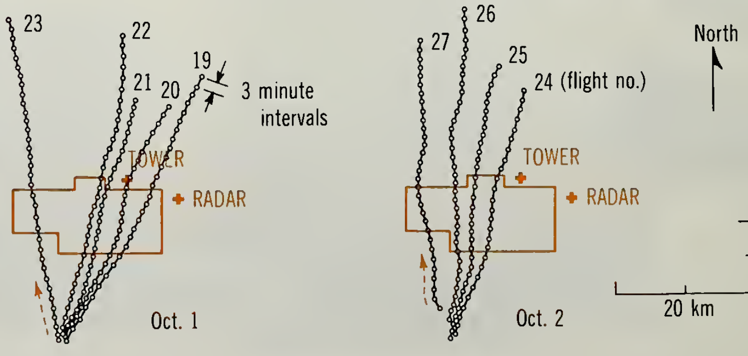
Air quality simulation modeling development and evaluation at the laboratory has validated an urban diffusion model that describes the distribution of automobile-generated carbon monoxide, evaluated a long-term prediction model applicable to Ankara, Turkey, and developed three air-quality simulation models for chemically active pollutants. A sensitivity analysis of available Gaussian dispersion models has been completed, along with a comparative study showing that the Climatological Dispersion Model performs better than the Air Quality Display Model. A short-term dispersion model has also been developed to evaluate the necessity of controlling emissions from aircraft. Other models developed here include one for relating air-quality measurements to air-quality standards. A new Fluid Modeling Facility, consisting of both water and air channels will permit Meteorology Laboratory scientists to model complex flow patterns, such as transport and diffusion of pollutants around buildings, mountains, valleys, and the like.

During the 1970's the laboratory is emphasing the validation of diffusion models for chemically reactive pollutants and the evaluation of new modelling techniques. Diffusion models will be evaluated under the auspices of the Regional Air Pollution Study in St. Louis, Missouri. Programs will be devoted to solving problems on plume downwash around buildings, topographical effects on plume rise and diffusion, air-water interactions involving pollutant transformations, small-scale dispersion from traffic, and environmental impact of elevated or depressed highways and airports. The User's Network for Environmental Quality Modeling was implemented in 1973; this concept involves using the latest technology in computer hardware and software to set up a library of simulation models and related data that are readily available to all potential users.

Other research programs are devoted to the description of transport and dilution of airborne pollutants originating from large single sources — for example, power generating facilities. Efforts are directed toward describing the dispersion and physicochemical changes of effluent (pollutants, water vapor, and heat) from large single sources; and developing and evaluating natural precipitation-scavenging models that describe the pollutant washout attributed to ground level contamination from the pollutant emissions of large power generating plants.

The laboratory has completed field tests under auspices of the Large Power Plant Effluent Study (LAPPES) in western Pennsylvania, yielding a large body of data currently being analyzed to describe the ultimate disposition of pollutants emitted from stacks 700 to 1,000 feet high. It has also discovered indications that absorption-desorption processes are important in the natural precipitation scavenging of sulphur oxide in the atmosphere. Major considera-

Tetroons are constant-pressure-level balloons used to trace the atmospheric thermodynamic contours of the urban atmosphere. At left, one is shown drifting over Manhattan. An Oklahoma City study (diagram) has helped define the ways in which a city changes the local atmosphere. At right, an 800,000-cubic-foot balloon launched from Holloman Air Force Base carries a new nitric oxide sensor toward the stratosphere. These were the first in-place nitric oxide measurements obtained there in an experiment conducted under the Transportation Department's Climatic Impact Assessment Program.



tion is being given to the heat and moisture budgets of a power plant cooling pond, to determine the contributions of sensible heat and moisture to the atmosphere from such a cooling facility.

Geophysical programs at the Meteorology Laboratory are attempting to describe the effects of air pollutants on weather and climate, identify regions likely to have "acid rain" problems determine the dependence of urban-rural radiation (solar, terrestrial, global) differences on atmospheric pollution and urban morphology, and describe air pollution potential climatology for the United States, in forms that can be applied to land use activities and strategies. A precipitation chemistry network involving 10 sampling stations at National Weather Service sites has been put into operation, supported jointly by the Meteorology Laboratory and the Environmental Protection Agency's Chemistry and Physics Laboratory.

Meteorology Laboratory scientists are deeply involved with the Environmental Protection Agency's Regional Air Pollution Study (RAPS), a five-year research program initiated in July 1972 that will bring together a number of areas of research. These include air pollution effects, atmospheric processes, monitoring and analytical methods, ambient air quality surveillance, and source characterization and control strategies. These field studies will be carried out in the St. Louis area and the Environmental Protection Agency will coordinate the RAPS with the experiments of other private groups and Federal agencies there. The RAPS is recognized as a means for the Environmental Protection Agency to determine how well the effectiveness of air pollution control strategies may be assessed and predicted within an air quality region, and to provide a basis for developing improved control strategies.

The major data sources in the St. Louis area will be a very detailed emissions inventory and a network of instruments measuring air quality and meteorological parameters. Stationary sources will be studied to determine the chemical content, release schedule, and physical characteristics, such as release heights, of each significant emission. Air quality monitors will be installed and operated at some 20 to 30 fixed sites and their data telemetered automatically to a central computer for immediate initial evaluation and storage. Some of the stations will measure meteorological variables.

Other sources of information will include soundings by helicopter to determine the vertical distribution of pollution, balloon soundings of meteorological parameters, and aircraft sampling over longer ranges. Tracers will be added at selected sources to help identify pollutants for studies of mixing and the chemical transformations resulting therefrom. A great effort will be made to understand the chemical and physical changes that occur during transport by the atmosphere, and this will require the collection of many samples and their prompt analysis in nearby laboratories, including mobile laboratories.

All field activity is expected to be completed by the end of 1977, but the analysis of RAPS may continue for several years, and should have considerable impact on air pollution simulation and air quality models, verified versions of which will begin moving to state and local air pollution agencies during this period of data analysis.

Constant volume balloons have been used by the Air Resources Laboratories to study the mesoscale and planetary-scale air flow for a number of years. The influence of an isolated urban area on the three-dimensional air flow was estimated from tetroon flights across Oklahoma City in the fall of 1971. This project involved 32 tetroon flights on 10 days with a relatively strong (about 13 meters per second) southerly flow. The tetroons, with transponders attached, were ballasted to float 300 meters above the ground, and were tracked by the M-33 radar obtained from the Air Resources Field Research Office in Idaho Falls.

Over the city in the morning there was a mean (tetroon) trajectory turning toward lower pressure of about 10 degrees. This turning, presumably frictionally induced, was noted only weakly in the afternoon and not at all in the evening, but there was slight evidence for a bending of the trajectories around the city at these later times.

The pattern of vertical air motion in the Oklahoma City area, as estimated from the restoring force acting on the tetroons when they were displaced from their equilibrium float surface (300 meters), indicated a plume of ascending motion extending at least 30 kilometers downwind of the city. Basically, this plume effect results from the observation that the tetroons, though forced considerably above their equilibrium float surface upon approach to downtown, did not descend until some distance downwind of the city, implying a sustained upward air motion.

The tetroon-transponder system appears to be a feasible way of examining spatial variations in stress, and should prove useful in mapping the stresses associated with natural and man-made objects and in evaluating the representativeness of stress estimates at specific tower locations.

On a larger scale, temporal and longitudinal variations in mean meridional (north-south) wind in south temperate latitudes have been estimated from 46 GHOST constant level balloon flights at 100 and 200 millibars between 1966 and 1971 and from 46 EOLE constant level balloon flights at 200 millibars in 1971-1972. At these latitudes there is evidence each year for about a 30-centimeter-per-second poleward flow in winter-spring and equatorward flow in summer-autumn, with the oscillation at 100 millibars preceding that at 200 millibars by a month or two. This alternating flow due almost entirely to large seasonal variations in mean meridional wind over the South Atlantic, may be partially responsible for the annual variation in total ozone in south temperate and polar latitudes. Superimposed on the above seasonal variation is a 10-centimeter-per-second poleward flow during the east wind phase, and equatorward flow during the west wind phase, of the quasi-biennial zonal (east-west) wind oscillations in the lower tropical stratosphere, suggesting an extension of the quasibiennial oscillation to temperate latitudes. At 200 millibars there is a mean equatorward drift of 4 centimeters per second, but there is little evidence for a drift at 100 millibars, presumably indicating the upper limit of the Ferrel (indirect) circulation. In the annual average the equatorward flow exceeds 20 centimeters per second to the east (lee) of the Andes Mountains, while a smaller equatorward drift is found over the south Indian Ocean. Over South Africa and Australia the mean flow is toward the pole.

THE CLIMATIC IMPACT ASSESSMENT PROGRAM of the Department of Transportation was established to investigate the environmental impact of a fleet of high-altitude transport aircraft projected to be operating by 1990. It has been postulated that some of the jet exhaust products may act as catalysts in destroying ozone. If so, the naturally occurring protective layer of ozone that absorbs shortwave ultraviolet radiation from the sun may be affected, resulting in increased ultraviolet radiation reaching the surface. This could have serious biological consequences.

The Air Resources Laboratories are participating in two aspects of the Climatic Impact Program relating to the possible effects on the ozone layer and their consequences. One in cooperation with York University in Toronto and Utah State University, is the development of a balloon-borne chemiluminescent stratospheric nitric oxide detector. The purpose is to measure the current levels of nitric oxide in the stratosphere up to about 70,000 feet. This will provide a basis for assessing the impact of additions from the high-altitude jet transport fleet.

The second part consists of a program to monitor ultraviolet solar radiation reaching the ground at two National Weather Service stations, Bismarck, North Dakota and Tallahassee, Florida. (Other investigators are studying the consequences on man and the biosphere of a change in the ultraviolet radiation.) For this activity, NOAA has modified two Dobson spectrophotometers to respond as dosimeters in the erythema (or skin-reddening) portion of the solar spectrum (2900 to 3250 Å). The relative response curve which has been carefully reproduced in the two instruments was

provided by Dr. F. Urbach of the Temple University School of Medicine. The instrument modification resulted in what is probably the most accurate one now in use anywhere in the world.

The data analysis will consist of comparisons of the amount of incident solar energy in the erythema range with total ozone, turbidity, conventional solar radiation, cloudiness, and perhaps visibility. The aim is to establish an empirical relationship between these several elements and the erythemal energy. This relationship can be used at other locations where only weather data are available. Further, a number of theoretical relationships have been formulated to predict the erythemal response to changes in ozone and turbidity; these will be tested with the data to be collected during the coming year.

The Atmospheric Physics and Chemistry Laboratory is also involved in the Climatic Impact Assessment Program. An upward-looking infrared radiometer mounted on WB-57F (Canberra) or U2 aircraft measures the long-wave emission from atmospheric water vapor above flight level, an electrochemical concentration cell measures the ozone content of air drawn in by a probe on the aircraft, and the ion concentration in the air is measured by collecting the ions in an electric field in a drift tube. The objective of these measurements is to gather data on the distribution of water vapor, ozone, and dust particles in the stratosphere over much of the western hemisphere (from Alaska to Argentina and San Francisco to Norfolk) and also to measure the water vapor, ozone, and particles supplied to the stratosphere by the giant thunderstorms of the central United States and the Intertropical Convergence Zone. With this information available, the annual turnover of water vapor in the stratosphere can be estimated with greater accuracy than in the past, and this figure can be compared with the calculated annual release of water vapor in the stratosphere by future high-flying aircraft, to determine whether such aircraft significantly affect the natural levels of these constituents. In addition to the field program, some mathematical modeling of the possible reduction of available solar energy by suspended dust particles is being done to determine whether the particle emissions by aircraft in the stratosphere cause any significant climatic cooling.

Infrared radiometry and thermal imaging techniques are utilized by the laboratory to study the thermal properties of land and sea surfaces, to map the distribution of hail on the ground during and after thunderstorms, to measure free-air temperature from aircraft without lag, airspeed corrections, or interferences by liquid water or ice, and to study seeding-linked changes inside clouds in the thermal and radiative properties of clouds.

Nuclear Tests, Nuclear Power.

Meteorological support for nuclear testing comes from an Air Resources Laboratories group in Las Vegas, Nevada, which provides the meteorological services required in support of the Nation's nuclear testing program administered by the U.S. Atomic Energy Commission's Nevada Operations Office.

Operational support is provided primarily for underground nuclear weapons tests conducted at the Nevada Test Site, but is occasionally required for nuclear weapons tests and industrial applications of nuclear explosives at other geographical locations as well. For example, 12 members of the Las Vegas staff were involved in the field support of Project RIO BLANCO, the third in a series of experiments sponsored jointly by the Atomic Energy Commission and private industry aimed at proving the feasibility of stimulating natural gas production. RIO BLANCO is the first project to use three nuclear explosives fired simultaneously in one emplacement well. The well is located in the Piceance Basin of western Colorado, about 50 miles north of Grand Junction.

In addition to the routine forecasting services provided for the test site, predictions of the transport of radioactive effluent and estimates of exposure levels potentially resulting from an accidental release of radioactivity to the atmosphere are provided for all underground nuclear explosions. These trajectory predictions and exposure estimates are used by test management for scheduling nuclear events, evaluating radiological hazards, clearing and controlling critical areas, and monitoring off-site areas. An extensive mesoscale observational network is employed to obtain measurements of pertinent meteorological variables.

This laboratory's applied research program is directed toward improving its meteorological services, with particular emphasis on wind predictions, the basis for radiological safety planning. Studies continue on the development of numerical models for the prediction of mesoscale wind fields aloft. Using these numerical wind model results as input, development has continued on a numerical model for objectively predicting the movement of a suspended radioactive debris cloud through the atmosphere.

Extensive post-event analyses of radiological and meteorological data are prepared for all tests that release significant radioactive effluent to the atmosphere. These analyses provide the final documentation of the available radiation exposure data for those events and are used for the determination of accumulated exposures in off-site areas. The analyses are also used to develop improved analog models for the estimation of potential exposures resulting from accidental releases. A radiological dose-prediction model is also under development for seepage releases of gaseous fission products.

Work continues in support of the Plutonium Environmental Studies Programs of the Nevada Applied Ecology Group. This support consists of meteorological measurements and analysis of these measurements to determine relationships of meteorological variables to the resuspension and redistribution of deposited radioactivity. Recent efforts have concentrated on the development of meteorological measuring systems and data gathering at the specified sites at the Nevada Test Site.

NOAA scientists, under contract to the Atomic Energy Commission, are providing data on the meteorological aspects of nuclear tests and power reactors, and learning something about atmospheric trajectories at the same time. At left, a New Jersey reactor. At right, a smokestack and instrumented tower used in plume studies .

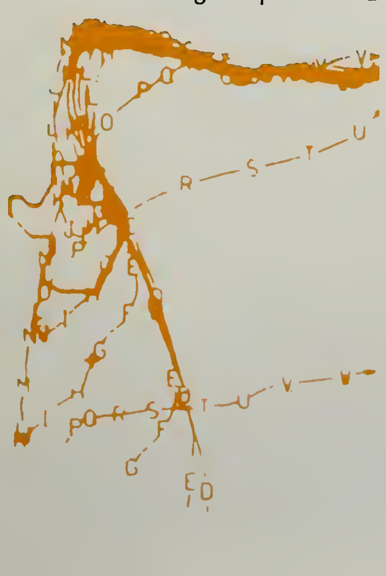
The Atmospheric Turbulence and Diffusion Laboratory at Oak Ridge, Tennessee, is the focus for research supporting Atomic Energy Commission-Oak Ridge National Laboratory requirements for expertise in these fields as they relate to siting and operating nuclear power plants and nuclear fuel reprocessing facilities, and to the environmental impact of power generation, including thermal discharge. The fundamental task is to understand and predict the capability of the atmosphere to disperse air pollutants. This requires study of atmospheric diffusion over all scales, and study of the turbulent lower atmosphere. Projects emphasize turbulence and diffusion over cities and in forests, since little is known about these areas compared with open terrain.

Work here includes plume-rise studies. Simplified diffusion calculations for small emissions have been developed, taking into account stack and building effects, positive and negative buoyancy, the urban night time mixing layer, and some terrain effects. Cooling tower plumes at the Oak Ridge Gaseous Diffusion Plant were observed in order to develop methods of relating the visible length of the plume and the probability of downwash to measurements on a nearby 30-meter meteorological tower. Observations of the deposition of chromate emitted from the cooling towers are being compared with a theoretical model of drift deposition.

Numerical modeling of planetary boundary layer flow is being used to estimate the effects of urban land use on surface temperature and the surface energy balance.

The simple model of urban air pollution has been extended to include photochemical reactions, dry deposition, and precipitation scavenging. The simple photochemical model was able to simulate observed variations in photochemical smog concentrations in Los Angeles as well as much more complex numerical models. Critical reviews are being prepared on the subjects of atmospheric effects of energy generation, plume rise, and modeling of flow and diffusion near buildings.

Laser probing of the particulate distribution over Oak Ridge is performed on a routine basis throughout the year. Information obtained is analyzed in order to determine the hourly variation of scale height, turbidity, and vertical diffusivity.



In compliance with the National Environmental Policy Act of 1969, the Air Resources Laboratories have the responsibility to review for the Department of Commerce the atmospheric pollution aspects of environmental impact statements issued — about 100 per year — by the Government for facilities under their jurisdiction and control. In this role, the laboratories produced a regional study of the meteorological aspects of developing 30,000 megawatts of fossil-fueled power in the southwestern part of the United States. In order to validate the diffusion model used in this study, especially with regard to the effect of mountainous terrain, a series of tracer releases in a deep canyon were made and diffusion rates were measured and related to meteorological parameters.

Research into the meteorological aspects of nuclear reactors is directed towards current and anticipated environmental problems associated with the release of radioactive effluent wastes to the atmosphere. As part of an effort to determine the transport and diffusion within the planetary boundary layer a number of field studies have been carried out.

A month-long series of meteorological measurements at Haswell, Colorado, made in cooperation with the Wave Propagation Laboratory (see page 42), used a 30-mile radius surface wind network and the mobile M-33 tracking radar from the Air Resources Laboratories Field Research Office in Idaho to follow constant-volume balloons. Wind and temperature measurements were obtained from a 154-meter meteorological tower and a series of indirect measurements of atmospheric properties by laser and acoustic sounding techniques by the Wave Propagation Laboratory.

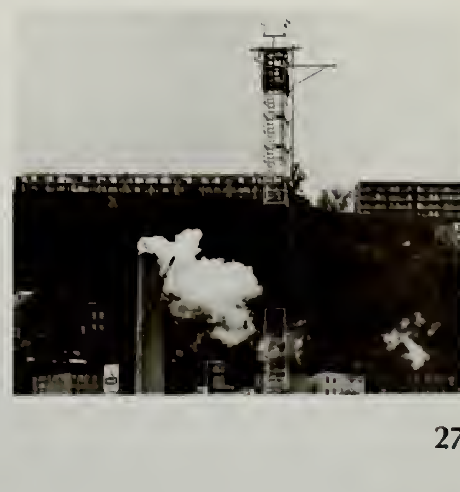
Atmospheric tracer tests at the National Reactor Testing Station involved the simultaneous release of six different tracers — uranine dye aerosols, Krypton-85, methyl iodide, sulphur hexafluoride, and two freon gases — with concentrations measured on arcs with radii out to 100 kilometers. Another series of tests monitored atmospheric tracers released from a 600-foot stack in a 5,000-foot deep canyon. This study was conducted to determine the effect of rough terrain on atmospheric dilution rates.

Advisory and technical assistance functions to the Atomic Energy Commission continue in the meteorological review of Safety Analysis Reports for nuclear reactor licenses. Also, during launches of spacecraft carrying nuclear power sources (for example, Apollo 17 and Pioneer) a laboratory meteorologist serves at the Kennedy Space Center on the staff of the Radiation Control Center to give meteorological assistance in the event of a launch pad abort in which radioactivity is released to the atmosphere.

Over the years, balloon, aircraft, and surface sampling systems have provided data on radioactive tracers resulting from nuclear testing, nuclear reactors, and natural processes. These tracers have been used to construct models of the stratospheric circulation, stratospheric-tropospheric exchange, interhemispheric mixing, and the expected time of deposition and latitudinal distribution of debris injected into the stratosphere. A computer model has also been developed for predicting local fallout from various types of nuclear detonations that inject debris into the atmosphere.

Chinese and French nuclear tests continue to provide opportunities for studying stratospheric transport and interhemispheric exchange. The extension of the Hadley Cell circulation to the lower tropical stratosphere has been demonstrated from these data. Available data on excess (bomb-produced) Carbon-14 in the atmosphere have been compiled and atmospheric inventories computed quarterly (or as the data warrant) from 1955 through 1969. Carbon-14 is used as a tracer of carbon dioxide and has yielded new information on the rates of exchange of atmospheric carbon dioxide with the oceans and biosphere. The balloon-borne molecular sieve samplers developed for the Carbon-14 program, as well as several other techniques, are being explored for possible use in measuring other trace constituents in the stratosphere.

These studies are being integrated into a broad program of basic and applied research oriented toward understanding the impact of the general circulation of the atmosphere on the movement of trace materials and the reverse impact of the trace substances on the general circulation. Toward these goals, major emphasis is placed on studies of the atmosphere's energy budget and the measurements of various trace constitutents that are noted either for their impact on climate or their utility as tracer elements.



The Environment of Ocean

NOWHERE IS LIFE more bound to its physical surroundings than in the sea, where all creatures feel the constraints of filtered light and abyssal darkness, patches of rich "pasture" drifting in the oceanic desert, meandering currents, and rising, sinking, twisting surfaces of temperature and water composition. Environment spins the plot; the inhabitants of the sea are only players, driven by instinct and necessity to respond to processes which envelop and largely control them.

And we, although less rigidly, are also players here, strongly influenced moment to moment, day to day, epoch to epoch, by seemingly remote events occurring in the sea, or the land beneath the sea, or the ocean-covering atmosphere.

We live on continents rafted apart with geologic slowness by a spreading seafloor, and there is evidence that the minerals we tap ashore are a kind of geotectonic gift from the sea. Much of what we read in our continental skies was written along the boundary between atmosphere and ocean. In the marine world of predators, we are the preeminent predator; but, irresistibly, the search transcends the hunt. There are reflexes which work toward comprehending this global blend of coarse and delicate, obvious and masked interactions. This search for new knowledge of the marine and lake environments, and their confrontations and accommodations with the human world, are reflected by the varied dimensions of the ocean- and Great Lakes-looking work of the Environmental Research Laboratories. Beginning more than a decade ago as small research projects in the former Coast and Geodetic Survey (and more recently than that along the Great Lakes) this effort now seeks to see these complex environmental systems whole. It has three centers of action within NOAA's research arm: the Atlantic Oceanographic and Meteorological Laboratories, in Miami, Florida; the Pacific Marine Environmental Laboratory, on the Seattle campus of the University of Washington, and its Joint Tsunami Research Effort, on the Honolulu campus of the University of Hawaii; and the Great Lakes Environmental Research Laboratory, in Ann Arbor, Michigan.

Much of the work at these centers is linked to research activities of colleague laboratories within NOAA — the laboratories of the National Marine Fisheries Service, for example — and to investigations in universities and private industry. Individuals and institutions receiving support from the NOAA-administered Sea Grant Program often share projects, information, expeditions, and objectives with the laboratories, as do participants from many state, regional and international research organizations.

The Motions of the Sea

Even if nothing lived in the sea, there would be the great oceanic vitality, the endless movement, the intricate internal exchanges of energy and matter, and the dynamic links with the overlying atmosphere. Scientists at NOAA's oceanographic laboratories are concerned with the entire spectrum of this vitality, from high-frequency wind waves to low-frequency phenomena like tides and longer-term sea-level changes, and with the ways in which water transports nutrients and heat, and influences weather, pollution, and life in the sea.

At the Miami laboratories, the deep-water emphasis has been on improving the description of large-scale ocean circulation, with an eye to developing methods of modeling and predicting it. A major project there has been a comprehensive study of the Gulf Stream, made in cooperation with NOAA's National Ocean Survey, that is now becoming available in the form of published measurements and scientific reports providing new understanding of this complex system. Other projects center on the ocean current regimes off the east and Gulf coasts of the United States, and their regions of generation and modification in the trade wind, Caribbean, and Antilles Current regions.

The Gulf of Mexico is to the southern crescent of the United States what the Great Lakes are to the northeastern states, and shares many similar problems. A series of multiship investigations (follow-ons to ongoing CICAR and EGMEX studies*) continues to explore the Gulf Loop Current, which is formed by the Yucatan Current flowing north into the Gulf and turning southeastward to exit through the Florida Strait, and which is dynamically quite complicated. For example, heat storage in the Loop Current is suspected to influence not only the position of the loop, but also the size and intensity of hurricanes crossing the current. The descriptive work here covers the heat, water, and chemical budgets throughout the Gulf which relate to hurricanes, contintental rainfall, biological productivity, sport and commercial fisheries, pollution potential, and other features touching the quality and safety of life along the Gulf coast.

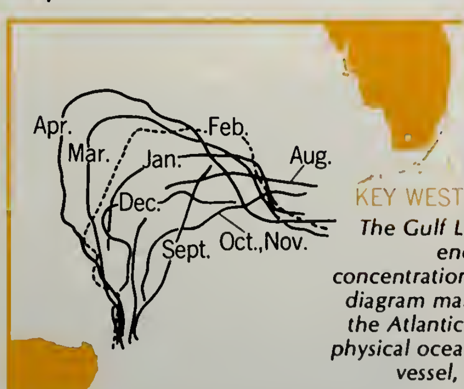
The complex roles of various scales of oceanic motion provide the focus of MODE,** a multinational project conducted as part of the International Decade of Ocean Exploration. In this investigation, traditional circulation-observing tools — for example, submerged current meters and drogue buoys — are supplemented by new "robot" tide and current-measuring devices, and data links between sensors, ships, buoys, and earth-orbiting satellites. A parallel program seeks to increase the precision with which oceanographers now measure standard water properties. Given such improvement, geochemical tracers — exotic constituents of seawater — could be used to measure exchange rates among the semi-isolated Gulf, Caribbean, and Atlantic basins, and to monitor the coastal discharge and dispersion of pollutants.

Ocean tides, the low-frequency waves generated by the gravitational attraction of moon and sun, are the other side of the ocean circulation research program. Although tides in coastal areas are possibly the most predictable of terrestrial phenomena, not much is known about global tides except what has been inferred from coastal and island observations. At the Miami laboratories, offshore observations of tides are being used to verify and refine present mathematical models of global tides, models which may finally be used to predict tides at coastal points from first principles. Present studies emphasize finding the "action centers" — the points where the tidal oscillations reach their maximum amplitudes — in the deep ocean, measuring the tidal modifications introduced by the continental shelf, and determining the mechanisms which reflect tidal energy back to sea from the continental margins. The tool of this trade has become a Miami-developed (with the National Ocean Survey) deep-sea tide gage that can be deployed from a ship and its vital components retrieved after a sufficient data-gathering period has elapsed.

Although the Pacific Marine Environmental Laboratory's research on the movement, composition, and properties of Pacific Ocean waters is less extensive than the Atlantic effort, much has been done here to describe micro- and mesoscale water motions on and in the open ocean. A cooperative undertaking with the University of Washington is studying the causes and effects of internal waves. Internal waves, apparently the turbulent residue of tidal energy, are believed to be one of the important mechanisms for energy transfer in the ocean, providing one of the few avenues for significant energy flux through the thermocline into or out of the oceanic mixed layer. Thus, these incompletely understood phenomena must be considered in any calculation of oceanic and air-sea energy budgets.

Internal waves of tidal frequencies are also the subject of study. Associated with continental slopes, seamounts, and other regions of large changes in ocean depth, internal tides seem to be generated by interactions of a rough seafloor and ordinary tidal motions. Experiments have shown that semidiurnal internal waves are propagated seaward from the continental terraces as the tide moves across it, and follow-on studies are attempting to quantify the energy content and distribution of these internal waves.

Related research by the Joint Tsunami Research Effort is developing electromagnetic techniques to provide rapid and accurate measurements of both vertical and horizontal electric fields which yield water mass transport on a large scale. The Miami facility has also been developing methods of using acoustic signals to detect and monitor internal waves with an eye to determining their place in the overall dynamics of the sea. Circulation on the continental shelf combines the complexities of estuarine circulation with those introduced by surface, planetary, and edge waves. A research investigation off the Washington coast is measuring and modeling net circulation and its variance as a function of wind and density fields. Other investigations in the Seattle laboratory's program include studies of turbulent diffusion, which plays an important but poorly understood part in effluent disperson; examination of the water-sediment interface, with an eye to the dynamic coupling of sediments and water in the boundary region; and a study of seawater thermodynamics, needed to meet the growing hazard of estuarine and coastal thermal pollution.



The Gulf Loop Current has profound effects on the regional energy budgets, maritime storms, fisheries, pollution concentrations and a host of other factors influencing life. This diagram marks the positional shifts of this important focus for the Atlantic Oceanographic and Meteorological Laboratories' physical oceanography effort. At left, the laboratories' research vessel, **Virginia Key,** *the main platform used in the Loop Current project.*

*From Cooperative Investigation of the Caribbean and Adjacent Regions, and Eastern Gulf of Mexico Experiment.
**From Mid-Ocean Dynamics Experiment.

Tsunamis, the destructive wave-trains generated by submarine and coastal earth movement, are mainly creatures of the seismically active Pacific Ocean. The Joint Tsunami Research Effort is studying tsunamigenic source regions, open-ocean propagation characteristics of the passing wave train, wave effects at the shoreline, and methods of providing tsunami hazard maps to state and local authorities, underwriters, and developers. These studies aim at improving the effectiveness of NOAA's Pacific Tsunami Warning System, operated by the National Weather Service from an observatory in Honolulu and a regional warning center at Palmer, Alaska.

Some of the interesting byproducts of this research have been the deployment of the first instruments of what will eventually be an open-ocean tsunami monitoring network, with sensors installed below ocean station vessels and data buoys (as these become operational). These devices are also being used to measure deep-ocean tides in a study partially supported by the Atomic Energy Commission. An electric field installation made at Honolulu Observatory by the tsunami researchers is being used to measure planetary and internal waves as well as tsunamis. A second electrode installation was made on Bermuda to obtain large-scale measurements in the MODE area simultaneously with other deep-ocean wave measurements there.

From the standpoint of life ashore, the most important motions in the sea may very well be those which link the ocean and atmosphere. Sea-air interaction studies at the Miami facility seek to describe and comprehend the dynamic physical and chemical components of that linkage, at virtually all scales. Conventional laboratories are not involved here, for in much of the work the laboratory is either a mathematical world or the marine environment itself.

The interface of air and water is a critical gateway through which quantities of energy and matter enter and leave the ocean, and so even micro- and mesoscale events here are important to sea-air research. Laboratory experiments seek to simulate flows along the actual atmosphere-ocean interface, not so much as scaled-down models (water refuses to be scaled down) but as "sections" of various turbulent processes. Investigators here are studying the dynamics of wave growth, with particular attention to the role of fetch and wind speed in wave development.

A study of the planetary boundary layer seeks to describe the major features of this mile-thick fluid mantle of air and ocean. Conducted with the University of Miami's School of Marine and Atmospheric Science, the investigation measures vertical profiles of wind, temperature, humidity, direct fluxes near the sea surface, total heat exchange across the air-sea interface, and variations of temperature from the surface to the thermocline. Useful mathematical models of these processes are a key objective here.

This general area of study has begun to produce interesting results. A cooperative study (with Soviet scientists) recently indicated that maritime rainshowers are self-limiting because they inhibit convection in the mixed layer, and so reduce the flow of energy from sea to atmosphere. This work also suggested that mixed-layer measurements could provide better rainfall-at-sea estimates than conventional shipboard raingages.

This work is also generating new sensors. The Miami facility has been using an airborne laser profilometer and microwave radiometry to measure sea state, wave amplitudes, and the like, and, as part of a SKYLAB underflight program, has obtained the first microwave radiometric measurements of the waves beneath a mature hurricane.

Because the sun is prime mover of air-sea processes (and almost everything else), studies of solar radiation and its effects on the 100-meter oceanic boundary layer are part of the Atlantic effort. The objective is to develop better initial conditions for mathematical models of ocean and atmosphere, but a recurring byproduct is the "recalibration" of some types of conventional wisdom about sunlight and the sea. For example, researchers have obtained indications that turbidity and the consequent loss of sunlight may not be the culprit in the death of Florida's offshore coral reefs. And studies of solar radiation made at tropical island stations suggest the amount of solar radiation heating the tropical oceans is 15 to 20 percent greater than earlier climatological estimates showed. This implies that poleward heat transport by oceanic (and atmospheric) circulation is much greater than previously believed, an important consideration for long-range weather forecasting.

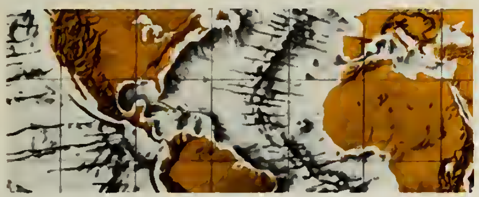
The Seattle laboratory, in its ventures into air-sea interaction research, has stressed the study of mesoscale processes in and between the uppermost 100 meters of ocean water and the lower atmosphere. The North Pacific setting of this experimental series provides high-latitude data of great utility to other researchers (including some at the Atlantic laboratories) attempting to develop predictive models of marine environmental processes affecting weather, water properties and movement, and the behavior of marine life.

Scientists at the Pacific Marine Environmental Laboratory are also playing a leading role in CUE, the Coastal Upwelling Experiment sponsored by the National Science Foundation as part of the IDOE. Upwelling is a seasonal occurrence found off the west coasts of most major continents. Northerly winds,*together with the earth's rotation, tend to drive inshore surface waters out to sea, causing deeper, colder water to "well up" into the space vacated by the warmer surface waters. Although colder bottom waters are relatively lifeless, they are laden with nutrients — the detritus of the millions of plants and animals that have died and sunk to the bottom. In areas of upwelling, the nutrients from deeper water can cause an almost explosive increase in marine life, and a consequent increase in the number of edible fiwh. The CUE series has been conducted off the Oregon coast in cooperation with several universities, and looks toward an intensive examination of coastal upwelling off the northwest coast of Africa, one of the world's great fisheries.

As part of its participation in MODE, the Mid-Ocean Dynamics Experiment (of the International Decade of Ocean Exploration), the Miami laboratories have helped develop the deep-sea tide gage shown being deployed at left, and have used the French EOLE satellite to trace transmitting buoys adrift in the equatorial Atlantic, shown here with the University of Miami ship **Gillis**

*Southerly winds below the Equator.

The Ocean Basins—



Revolution and Resources

A DECADE AGO, the work carried out by the Miami and Seattle facilities was strongly, even centrally, geophysical. Scientists there were working on a revolution then, using magnetic, gravity, seismic, heat flow, and other marine geophysical and geological clues obtained at sea to evaluate the hypotheses of plate tectonics and continental drift.

During the 1960's these workers, with their colleagues in universities and other institutions, did much to confirm those theories. The earth's crust *is* apparently composed of large rigid plates which rest on the denser mantle material, and these plates are driven apart and into collision, continually renewed by material welling up from the mantle, continually destroyed where they subduct beneath adjacent plates and are forced back into the mantle. The plate tectonic revolution has been compared with that of the Copernican revolution, and rightly so — nothing in this neighborhood of science will ever be quite the same.

Nor will the research associated with these crucial discoveries. As the outlines of continental drift and plate tectonic theories were sketched in, and as the search for a more detailed comprehension of these processes and events began, Federal support for such research diminished greatly. As a consequence, much of NOAA's present work in this area is concerned with distilling what new knowledge there is in geophysical and geological data and samples already taken from the sea, and to applying this to understanding where and why mineral resources exist in the land beneath the ocean.

Marine geologists at the Miami facility are concentrating their attention on reconstructing the submerged outlines where the continents were once joined, believed to lie at about the 1,000-fathom isobath. In 1970, a unique set of five maps was published that described where and when Pangaea, the original universal continent, split into the two supercontinents, Laurasia, in the northern hemisphere, and Gondwana, in the southern hemisphere, and subsequently into the continents as we know them today.

Further development of continental drift details and further proof of drift hypotheses require close analysis of continental margin shape and composition. The Atlantic laboratories are working out such detailed descriptions for the Caribbean, Gulf of Mexico, and North Atlantic, in an effort to determine whether there is a morphologically and geologically plausible fit between Europe and North America.

The TransAtlantic Geotraverse (or TAG) aims at establishing a standard crustal section along a 240-mile-wide great circle corridor between Cape Hatteras and Cap Blanc (Mauritania). The Atlantic traverse extends the Transcontinental Geophysical Traverse of the U.S. Upper Mantle Project, which crosses the United States.

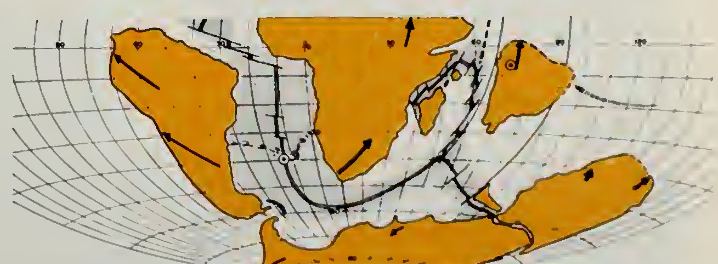
A closely related project is establishing a standard magnetic sequence calibrated according to accepted magnetic time scales across the entire TAG corridor. This chronology should describe the history of seafloor spreading rates and directions in the central North Atlantic, serve as a standard of comparison with other ocean basins, and provide a key to comprehending the complicated spreading processes at work in such adjacent plate areas as the Caribbean region.

Interest in geotraverse results has become commercial as well as scientific, as the hypotheses under investigation have begun to revise existing conceptions of how and where certain undersea resources occur. In 1970, TAG investigators found geological structures beneath the deep sea floor off the African continental shelf that resembled salt domes, a feature often associated with petroleum deposits. This was the first evidence in the Atlantic that such oil-trapping formations occur seaward of the continental shelf beneath the deep ocean floor, a fact subsequently confirmed by oil exploration surveys. The TAG program has also identified some dredged samples as unusually pure manganese crusts; these samples, dredged from the median valley of the Mid-Atlantic Ridge, are believed to be the first *hydrothermal* manganese ever found in the deep ocean, suggesting that mineral-forming processes occur as part of the seafloor spreading process.

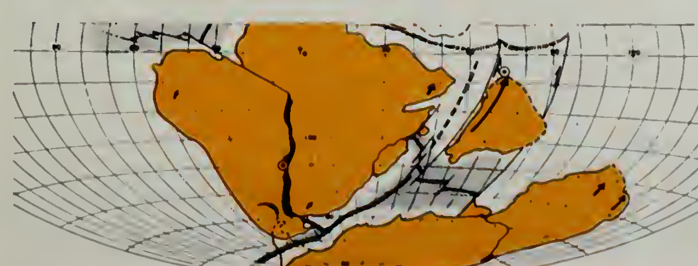
Although a good general understanding has been obtained of the distribution of sediments in the deep ocean basin, much remains to be learned about the processes which control that dis-

The time and direction of continental drift has been the subject of considerable study by NOAA marine geophysicists at the Miami laboratories. Shown here is a proposed sequence for one of the ancient supercontinents, Gondwana, and the paths and spreading centers behind continental motions.

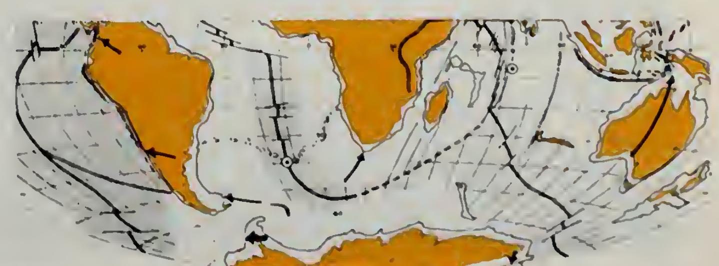
TRIASSIC -180 m.y.



CRETACEOUS -65 m.y.



JURASSIC -135 m.y.



PRESENT

tribution. The spreading seafloor hypothesis raises the questions of how the type and properties of sediment in zones of new crust are affected by the slow intrusion of mantle material. The instability of some submarine sediments, demonstrated by turbidity current deposits on the seafloor, requires a scientific response; these and other depositional and erosional processes at work in the deep ocean affect any attempt to extract natural resources from or to place structures on the seafloor, as well as our understanding of how the ocean redistributes what we dump there.

The deep-ocean sedimentation program at Miami is mainly associated with the TAG project, with samples taken along the TAG corridor providing a profile of observations across several sedimentary environments. Samples will be studied for mass physical and chemical properties and age-related characterisitcs.

At the Pacific Marine Environmental Laboratory, such research has concentrated on ocean basin studies that delineate and describe the Pacific system of crustal plates. Much of the laboratory's early work, particularly its geophysical research, derived from the rich data returned by *Seamap** voyages, and described phenomena of virtually oceanic scale. The Seattle facility's *Seamap*-based accomplishments include:

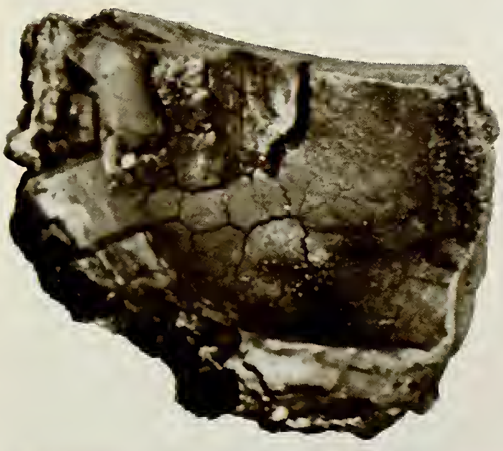
- completed bathymetry for a 250,000-square-mile area about 300 miles north of Kauai;
- completed bathymetry and magnetic anomalies of the area between 29 and 35 degrees north, and 155 and 165 degrees west (about 275,000 square miles);
- descriptions of the magnetic structure of the Aleutian and northeast Pacific basins, magnetic anomalies south of the Aleutian Island arc, and gravity anomalies over the Aleutian Trench.

But the trend of the Seattle laboratory has been increasingly detailed scales of significant discovery, and toward extensions of work done by the ocean survey. These investigations have described several previously unknown fracture zones (the Amlia and Adak fracture zones, and one south of Alaska named for the ship *Surveyor)*, the westward extension of the Murray fracture zone, a major volcanic province extending northwesterly from the Hawaiian rise, the Emperor fracture zone (apparently a major discontinuity in the earth's crust), and deep-sea channels south of the Aleutian arc. With the hardening of plate tectonic theory — already significantly advanced by *Seamap* and Pacific Marine Environmental Laboratory work — research at Seattle has emphasized related investigations.

An investigation of the Nazca Plate, made in conjunction with the University of Hawaii and Oregon State University, had its second field season in 1973. There, emphasis has shifted from describing the plate to determining which minerals are formed and concentrated by marine processes associated with the evolution of the Nazca Plate, and whether metal deposits are somehow redistributed over geologic periods of time and finally become the rich metallic mineral reserves we tap ashore.

There is also concern for the other side of the search for minerals. As deep ocean mining becomes an eventuality, the Environmental Research Laboratories have moved to investigate the impact of such activities on the marine environment and its life. Manganese nodules have always seemed quite promising for commercial mining, provided the technology of retrieving them became available — they are rich in copper, nickel, and cobalt, and offer alternatives to the depleted, environment-degrading, surface-mined reserves ashore.

In its first undertaking in the deep-ocean mining field, the laboratories are managing a study of an area 1,200 miles southeast of Honolulu that will make baseline measurements before, during, and after pilot mining operations. Investigators will attempt to gain an understanding of the physical, biological, and chemical setting of the study area, and how this setting is affected by mining. From this information, guidelines will be prepared for the large-scale mining operations expected to begin in the near future.



Marine geophysical activities in the marine laboratories have come to emphasize such man-centered processes as those controlling sedimentation (and so pollution) and mineral formation in the sea. At far left, a hydrothermal manganese sample dredged from the Mid-Atlantic Ridge, and the NOAA ship **Researcher,** *the Miami laboratories' primary deep-water platform. Below, the Seattle-based Pacific Marine Environmental Laboratory's prime platform, the NOAA ship* **Oceanographer.**

*From Scientific Exploration and Mapping Program, a systematic hydrographic, oceanographic, and marine geophysical survey program conducted by what is now NOAA's National Ocean Survey.

A Turn Toward Shore

For most Americans the ocean is that strip of water which abuts their city, one of the densely settled centers in which most of us live, and work, find our recreation, and dump the residues of population and culture. Land meets sea in the coastal zone, and so does man. The resulting problems of balancing our propensities to use and conserve, spend and save, are complicated in the extreme; and the national effort which addresses these problems is still quite new, and has far to go.

For oceanographers in the Environmental Research Laboratories, this gradual shift in emphasis has meant applying some of the skills and lessons learned at sea to the more delicate, detailed problems of the coastal environment. That, and revising old skills, for many deep-water oceanographers got that way because few scientists seemed to care about estuarine dynamics.

The Miami program is investigating those bottom or near-bottom processes presently active along the continental margin to develop an understanding of the movement of sediment and other sinkable matter from the shoreline across the continental shelf to the deep-ocean basin. Studies are also being made of the engineering properties (bearing capacity, cohesion, density) and geochemistry of submarine sediments, to obtain an improved understanding of such processes as submarine slumping, turbidity currents, and pollutant deposition. Known as COMSED (from continental margin sediments) this project is providing information on a rather large scale, as well as in a locally important series of experiments in the New York Bight.

Tides and tidal currents are perhaps the only physical processes in estuarine and open coastal areas that are anything like fully understood. And yet, important unknowns persist. Part of the Miami program is to improve present understanding of mixing rates, stratification, non-tidal flow, water-property gradients, and other events occurring along the narrow zone where fresh water meets salt, oceanic life is in part replenished, and human civilization confronts the ocean.

One such study involves the southeast Florida coast, in which the Atlantic laboratories are investigating environmental problems associated with offshore sewer outfalls along the southeast Florida coast and between the shoreline and Gulf Stream. The objective is to determine the residence time of the water into which some nine sewer outfalls presently discharge. Various techniques such as current meter and dye studies are being used to measure current patterns in this coastal strip, and to explain how these waters are entrained by the Gulf Stream. These studies will gradually be expanded up and down the coast, from Palm Beach to Key Largo.

Atlantic Oceanographic and Meteorological Laboratories scientists are also participating in what may very well be the most intensive study of a coastal body of water ever attempted — the New York Bight investigation of NOAA's Marine Ecosystem Analysis (MESA) program. The Miami laboratories are playing a major role there, studying mechanisms, pathways, and rates of sediment transport with bottom current-recording stations; taking bottom sediment samples; and using time-lapse photography. Particular emphasis is being placed on understanding the role of submarine canyons as possible conduits for transporting sea floor material, including dumped and discharged wastes, out into the deep ocean. Researchers are also attempting to comprehend the dynamics which shape the surficial topography of the nearshore ocean floor, and investigating variations in water quality, circulation, and mixing cycles in the Bight. These studies will be correlated with the biological data obtained by NOAA's National Marine Fisheries Service, to illuminate the interactions that control this important marine ecosystem.

Irresistibly, deep-water oceanographers are turning shoreward, to explore and explain the difficult interactions of man and coastal environment. At left, water samples are taken in the New York Bight, as part of NOAA's Marine Ecosystem Analysis (MESA) program there. Below, an eastern seaboard powerplant and the sun evoke the ecological problems of meeting energy requirements with new powerplants along the sea.

Coastal zone imperatives have also guided some of the Seattle research shoreward, toward detailed analysis, characterization, and modeling of estuarine and coastal processes. Puget Sound's main basin is the "laboratory" for these efforts to measure the combinations of fresh and salt water, temperature and turbidity, tides and river currents, bottom shape and sedimentation which make estuaries a difficult problem. Net circulation studies are being extended from the Sound into the Straits of Juan de Fuca (in cooperation with Canadian researchers), and will lead to estuarine study projects in Alaska, probably in conjunction with seasonal National Ocean Survey operations there.

The Great Lakes Environmental Research Laboratory, which was added to the Environmental Research Laboratories in 1974, has evolved from a small Great Lakes research program conducted by the National Ocean Survey and from the joint United States-Canada project called IFYGL, for International Field Year for the Great Lakes. IFYGL field work was completed in 1973, but analysis of the mass of hydrologic, atmospheric, and other environmental data has only just begun.

The limnologists at the Ann Arbor, Michigan, laboratory are applying an integrated, interdisciplinary approach to understanding the difficult and tangled problems of this heavily populated region. Lake conditions are pervasive here. High lake levels, as in 1973 and 1974, imperil shoreline homes and businesses. Low levels reduce channel depth for the Great Lakes' important shipping industry, and change the hydrology of an entire region. The lake water budget, and the associated flow in tributaries and connecting rivers, are fundamental quantities to be understood by these researchers.

Environmental quality is another. The high population density and industrial activity along much of the Great Lakes shoreline means that massive amounts of manmade and natural material continuously drain into the lake system. The transport and diffusion of chemicals and biological matter have great impact on lake biota, particularly in near-shore areas, and the new laboratory will develop methods of predicting these impacts, including such things as waste discharges from new powerplants.

New Vantage Points, New Sensors

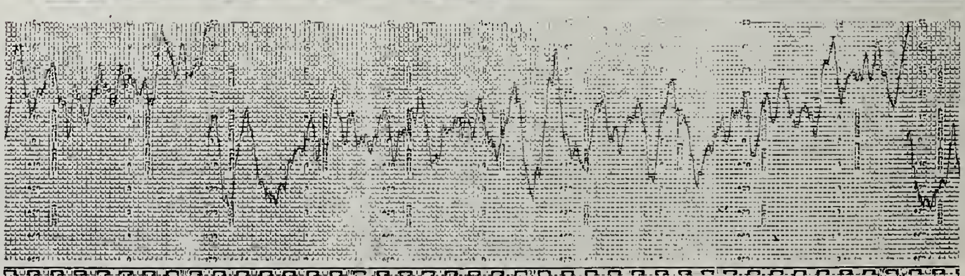
Since the first TIROS images began coming back from space, marine scientists have sensed they would benefit from this new environmental vantage point almost as much as their meteorologist colleagues.

The exhilarating color photography delivered by Gemini and Apollo flights extended this promise. Now, in the second decade of environmental satellite technology, platforms and sensors have become available that already offer oceanographers and marine biologists a wealth of data in a variety of useable forms, with more types of information and data products visible in the middle distance. The implications for ocean science services, fisheries management, shipping, and research should be profound.

The Atlantic Oceanographic and Meteorological Laboratories are working toward realizing some of the "wet" benefits of satellite technology, in an effort to learn how to apply tools and technology developed to monitor the ocean of air, to observing the ocean of water. From this experience, the Miami scientists are helping develop the guidelines for more strictly ocean-looking satellites and sensors now under consideration by the National Aeronautics and Space Administration.

At first glance it might seem that observing something as deep and generally opaque as the global ocean from space was a severely limited activity at best. The view is confined to the upper layers of the water and is essentially a two-dimensional one, with the crucial third dimension flattened almost to zero. However, this two-dimensional view can be used to describe the site of the principal interactions between air and ocean, and the region of most forms of economically significant marine life. In addition, a third dimension can be lengthened by mixing satellite data with oceanographic information obtained by conventional methods. Thus, satellite oceanography, as the new science is called, offers a way of monitoring the physical state of the ocean surface as well as some biological, chemical, and air-sea characteristics.

Visible imagery and ocean color from manned space flights and from the multispectral sensors aboard the first Earth Resources Technology Satellite (ERTS-1) have provided unique experience to the Miami researchers in interpreting the information available from space platforms. Applied to such areas as the New York Bight, such data have been able to detect acid waste dumping events, sewage sludge, various thermodynamic



surfaces, what appear to be the surface expression of long-period internal waves, and other interesting details. Also, viewing in different wavelengths permits deeper penetration of the water, providing a three-dimensional view of the upper layers of the ocean surface.

The color of the ocean is chiefly determined by organic and inorganic particulates of natural and man-made origin, by ice, foam, and spray, and by conditions of surface illumination. A deep, ultramarine blue is characteristic of sterile, clean, open ocean, while increasing amounts of chlorophyll-bearing plankton add to the green-yellow and red portions of the spectrum. Sediments tend to be brownish, with little spectrally differentiated character. In shoal areas, a white sea floor lightens the general tone, while vegetation tends to darken it. In the view of satellite oceanographers, ocean color is one useful approach to monitoring the marine environment from space. The Atlantic laboratories are pursuing this, using data obtained by ships, aircraft, and satellites.

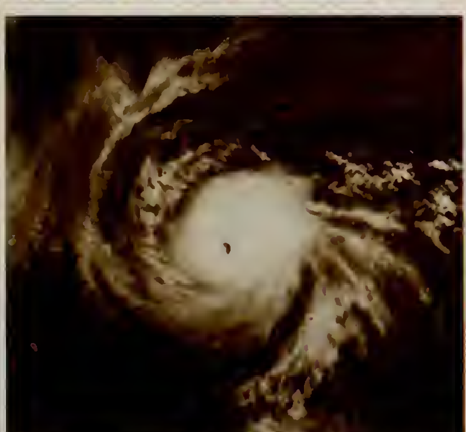
Other observable properties are temperature, texture, and topography. Spacecraft measurements of ocean surface temperatures are available now from NOAA satellites carrying infrared radiometers operating in the 10- to 12-micron atmospheric window, permitting the routine construction of sea-surface temperature maps to within a couple of degrees Kelvin, a useful precision.

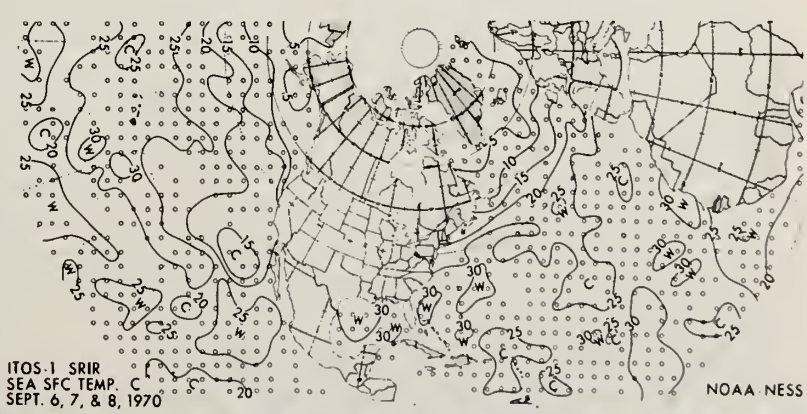
Microwave brightness temperatures have also been determined from aircraft with microwave radiometers; however, the technique appears to be more valuable in sensing the dynamic texture of the sea — sea-state, wave spectra, and the like. Because some storm systems are transparent to some microwave frequencies, this method has the added advantage of being able to sense sea-surface conditions benearth the storm's cloud cover, which effectively blocks visible and infrared scanners.

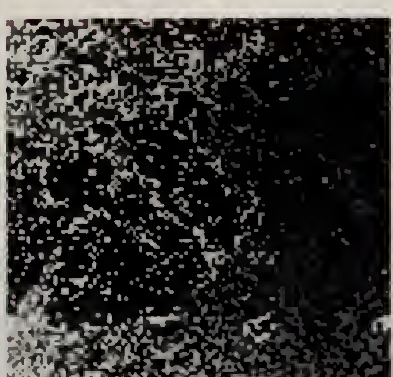
Precise radar and microwave altimeters aboard satellites are able now to measure the large-scale topography of the ocean surface. This means that the shape of the marine geoid and such broad-scale massive features as tidal undulations and major current systems can be inferred from measured changes in ocean surface topography.

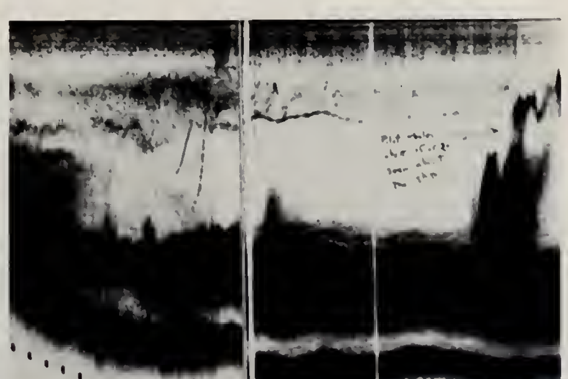
Beyond these presently available systems and techniques are the larger possiblities of satellite oceanography. Scientists at Miami, and their opposites in NOAA's National Environmental Satellite Service and the space agency, are working to make them an operationally useful part of the Nation's ocean research and service programs.

"Wet" products and projects, aimed at learning to measure oceanic processes from aircraft and earth-orbiting satellites, cover a wide spectrum of activity and energy. On the facing page are the ERTS-1 photograph of the New York Bight area, a NOAA-2 image showing the Gulf Stream off Florida, and a record from a laser profilometer aboard a NOAA aircraft. Below, left, a NOAA C-130-mounted microwave antenna was used in hurricane Ava penetrations to obtain ground truth data for the overflying Skylab instruments. A sea surface temperature map (below) is one of the operational products from NOAA's satellite technology effort. Microwave and acoustic techniques are in the vanguard of ocean remote sensing. Shown below are a microwave image of Arctic Ice (left) and acoustic record of ocean internal waves.









Simulated Oceans, Simulated Atmospheres

VIRTUALLY EVERY investigative province of the Environmental Research Laboratories includes some numerical modeling activity, but the principal effort is that concerned with simulating the *entire* planetary fluid system, and its internal interactions at various physical and temporal scales. This immensely complicated set of problems — very likely the most complicated set available to mathematicians and their computers — has been the focus of work at what is now the Geophysical Fluid Dynamics Laboratory since the middle 1950's, when numerical prediction work began in the former U.S. Weather Bureau. At this Princeton, New Jersey, laboratory, scientists and their electronic assistants are attempting to simulate and predict global processes in the atmosphere and ocean, extend the mathematical expression of various specific phenomena (for example, convection, internal waves), and advance the threshold of computer science and technology as these are applied to studying the physical environment.

Researchers in this broad area of fluid dynamic modeling are somewhat like constables tracking Wells' invisible man across a snow-covered field — they can make out footprints and see the quarry's cloud of breath, and that is all; there are many uncertainties in-between. At the Geophysical Fluid Dynamics Laboratory, the quarry is a family of models capable of simulating the general circulations of the atmosphere and ocean, global climate, and the perturbations and trajectories and interactions which both distinguish and connect them.

The advantage of simulation, of course, is that it offers the potential of reducing an earth-sized system to what amounts to a laboratory specimen. Then scientists can explore imaginary environmental Armageddons — dissipation of the ozone shield, oxygen depletion, gross global pollution of air and ocean — and see how the atmosphere and ocean behave with and without all their parts. A model may be put on a computer and run to destruction, to see what destroyed it, or run through without some important component, to determine the extent to which this removal has affected it. These instructive amputations of a hydrologic cycle, incisions into energy reservoirs, cultivations and cures of dynamic illnesses, applications and withdrawals of stimuli are contributing greatly to man's ability to look into the atmospheric and oceanic future.

Model Atmospheres

As weather forecasters, electronic computers require a point of view, and some means of expressing the atmosphere in their simple binary tongue. The point of view is that the atmosphere is deterministic at some scales; once set in motion, it responds predictably to the unfolding sequence of causes and effects, in accordance with known physical laws. Given sufficient, accurate information on the initial state of the atmosphere, then, a proper numerical model run on a large computer should be able to predict changes in atmospheric state at various scales, over various periods of time.

These imaginary worlds are systems of three-dimensional grids — volumes arranged on horizontal layers, like four-sided honeycombs on a wax wall. Atmospheric conditions are numerically described for each grid point, or intersection; then, this initial response is used as a foundation for the subsequent response, carrying the description forward one "time step." And so on, a simple set of operations, repeated over and over. It is the speed of repetition which makes computer models begin to lose their static composite appearance and begin to resemble the dynamic reality.

The first of the laboratory's models described atmospheric motion between the equator and 64 degrees north, at two layers of the atmosphere, on a 1,300-point horizontal grid. Subsequent models have been global in their coverage, and increasingly dense in their three-dimensional construction. A primitive equation (primitive means original here and refers to basic thermo- and fluid-dynamic equations) model developed over a decade ago — the forerunner of many of the current family of models — uses the five variables of temperature, pressure, two components of wind, and humidity, and solves for ten spherical atmospheric layers, at 10,000 grid points per layer. The researchers have since increased the number of grid points and layers, and go from the surface deep into the stratosphere.

Extensive analysis of the results from the numerical time integration of a global model of the atmosphere with seasons indicates that this model is capable of simulating the seasonal variations of the tropical rainbelt and major desert climates. Apparently, distribution of sea surface temperature controls the locations of the rainbelt in the model tropics and is responsible for the tendency of the rainbelt to avoid the equator. According to the comparison between two numerical experiments with and without the effects of mountains, the Tibetan plateau seems to be responsible for the abrupt onset of the monsoon precipitation in the Indian subcontinent.

The wave analysis is being extended to the middle latitudes of the general circulation model. At the same time a series of control experiments of tropical circulations will be performed to see the effect of the sea surface temperature on the preferred scale and position of tropical disturbances.

Two tracer experiments have been run for about a model year and are in advanced stages of analysis. The flow field required for such experiments is obtained from the numerical time-integration of the global model described earlier. The first is a diffuse point-source release of tracer into the lower stratosphere of the mid-latitude northern hemisphere. It thus is closely analogous to several well-documented releases associated with recent thermonuclear weapons tests. The second experiment simulates a vertically stratified tracer which is assumed to be in simple photochemical equilibrium at about 30 kilometers, dynamically controlled in the interior, and subject to removal processes in the lower troposphere. It can be visualized as being crudely analogous to atmospheric ozone.

These experiments can then be profitably compared to the behavior of their analogous tracers in the atmosphere. In the point-source tracer experiment, there is encouraging correspondence between the model simulation and the behavior of debris from thermonuclear weapons tests in the atmosphere. In particular, the strong poleward-downward slope of maximum isolines in the lower stratosphere, seasonal transitions, and the spring peak at the ground in mid-latitudes appear to be well simulated.

The second experiment shows structure and behavior which is closely analogous to atmospheric ozone. Features which appear to be well simulated are the large values of total tracer at the poles relative to the equator, poleward-downward slopes of mixing ratio lines in the lower stratosphere, strong gradients across the tropopause, late-winter build-ups in middle and high latitudes, counter-gradient horizontal eddy fluxes, strong downward transfer by large-scale eddy motions in mid-latitudes, interhemispheric differences, and local structure related to the jet stream and cyclone waves.

In addition to the relatively successful simulations, some qualitative general conclusions have been noted. Analyses of various zonal-mean balances for most cases show that in regions devoid of sources and sinks, a very strong compensation exists between the flux convergences by the large-scale eddies and the mean meridional circulation. However, during the seasonal transitions of the stratospheric circulation, significant decouplings of the usual mean cell-eddy balances occur, leading to strong changes in the tracer distribution at such times.

The results of the point-source experiment were also used to estimate the anticipated buildup of effluent produced by a hypothetical fleet of high-altitude jet aircraft. The results indicate that, relative to background values, small (less than 15 percent of background) values of perturbation water vapor values are expected in the vicinity of the maximum source region. On the other hand, perturbation concentrations of nitrogen oxides are expected to be as large as the background values or greater.

Special emphasis has been placed upon the construction of a mathematical

The Geophysical Fluid Dynamics Laboratory in Princeton, New Jersey, is NOAA's center of action for simulating the ocean and atmosphere mathematically. Shown here are the Princeton facility and some of the laboratory's modelers.

model of the atmosphere by which one can study the interaction between the upper atmosphere and the troposphere. A dynamical model which is particularily suitable for such a purpose has been designed, programmed, and tested, and yielded satisfactory performances. A scheme of computing radiative transfer in the lower mesosphere and stratosphere as well as troposphere has also been constructed and tested.

A numerical time integration of the joint mesosphere-stratosphere-troposphere model with very high vertical computational resolution will be carried out by use of the new computer (see page 41). It is hoped that this model can be used not only to determine how the upper atmosphere interacts with the lower atmosphere, but also to study global spreading of pollutants.

Modified versions of the general circulation model have been constructed to study the mechanisms and development of the mid-latitude cyclone waves. These models are now being used to examine the stability and structure of the frontal waves — that is, waves in flows containing both horizontal and vertical shear — and the interaction of released latent heat with the development of these waves.

Primary results from this work indicate that, with the presence of horizontal shear in frontal regions, the short (less than 2,000 kilometers) waves are most unstable. These waves are largely confined to the lowest 500 millibars of the atmosphere and have their maximum amplitude just above the planetary boundary layer. Their structure and energetics suggest that they are the intermediate scale cyclone observed in the atmosphere and the general circulation model. This work also suggests that the release of latent heat modifies the structure of the frontal cyclone wave so as to increase the conversion from eddy available potential to eddy kinetic energy, so that the waves develop at a much faster rate. In addition they extend through a deeper layer of the atmosphere than in the dry case although the surface disturbance is weaker. Scale selection appears to be the same as in the dry atmosphere.

As circulation models are extended to heights of 80 kilometers, it is expected that radiation will play a more important role than it does in the troposphere. An accurate and efficient radiative transfer routine is under development that will allow for the breakdown of local thermodynamic equilibrium and Voight line shape. The carbon dioxide transmission functions used are precomputed and provide a benchmark for assessing other less time-consuming methods. Water vapor is treated in a fashion similar to that used in present models. It is expected that the new model will first be used for sensitivity studies, and, with minor modifications, to problems involving the interaction of radiation and dynamics in the Martian atmosphere.

Work has been completed on the inclusion of moist thermodynamics into previously existing two- and three-dimensional numerical models of clouds. At present these models use the shallow anelastic equations and include bulk cloud physics effects. Three-dimensional calculations have been carried out for the simulation of observed tradewind cumuli with vertical wind shear present. These calculations have attained moderate success in that a cloud with qualitatively correct distribution of potential temperature and vertical velocity was obtained. The cloud also had a qualitatively correct vertical penetration and a realistic-looking down shear vertical tilt with height. The major shortcoming of the present simulation was that the cloud did not maintain itself over an extended period of time as the observed cloud did, but rather formed and dissipated over a period of approximately 20 minutes. It appears that present cloud models predict clouds which initially grow too fast and become too intense.

A two-dimensional numerical model has been developed that includes the detailed cloud physics involved in warm rain formation. This model was used to compare the results from three separate cases — bulk cloud physics only, cloud phase micro-physics only, and full cloud physics with warm rain production. The major conclusion was that the full cloud physics became significantly different from the bulk cloud physics only when the formation of balking raindrops was present.

A second model uses a parameterization scheme for treating the cloud phase microphysics. A comparison of the parameterized solutions with the more detailed microphysical model showed very good agreement. But comparison with nature is not considered possible at this stage of development. This effort continues toward improving the present three-dimensional numerical model for moist convection, including cloud droplets and rain droplets.

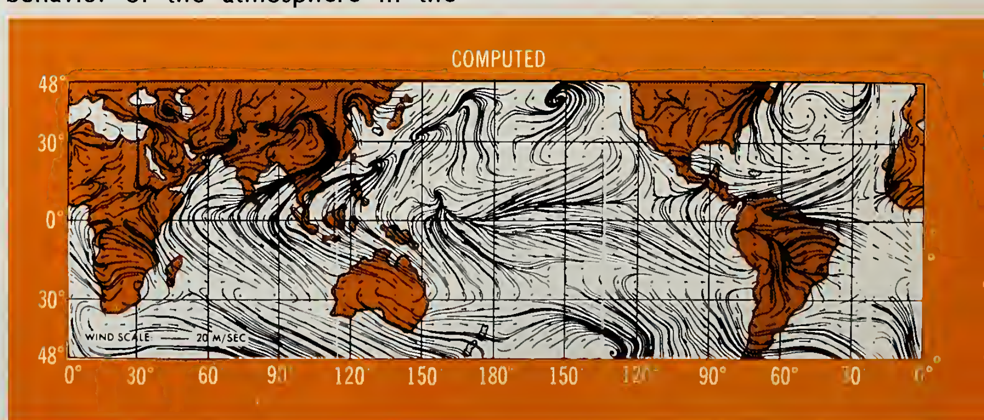
A two-dimensional numerical model has been developed to study the behavior of the atmosphere in the mesoscale range (horizontal scale less than 100 kilometers). The large-scale systems as well as the small-scale convection play a major role in the mesoscale dynamics. A related study has shown that the persistent diurnal oscillation of the atmospheric boundary layer is an important source of mesoscale internal gravity waves. The oscillation period of these waves is a function of latitude. A definite two-day period may be found in the equatorial regions with scales on the order of a few hundred kilometers. The similarity in the time and space scales suggests that observed cloud clusters may be originated by this process.

A study has been undertaken of the turbulence resulting from internal gravity waves reflecting from a region of different stratification. An existing salt water tank was modified to produce internal waves which propagate down into the tank and reflect from a region of constant density. Under certain conditions, the interaction of these waves in the reflection region results in local overturning and turbulence.

The application of this type of experiment to the ocean is significant. The ocean contains many different stratifications. Reflection of waves from these regions could produce overturning and vertical mixing, which may explain the structure seen in the ocean.

Internal gravity waves are capable of transferring both energy and momentum to the mean flow, through the mechanisms of nonlinear rectification, in regions of thermal excitation. Detailed calculations, involving both analytic and numerical models, have been carried out, which suggest that this effect may affect the equatorial zonal winds in the earth's atmosphere above 60 kilometers, and might also account for the "four day circulation" of the Venusian atmosphere.

A three-dimensional, eleven-level, primitive-equation model of a tropical cyclone has been integrated. Starting from a weak vortex in a conditionally unstable state, a strong vortex developed in the model and the almost moist neutral state was obtained near the vortex



center. The model simulated the outer spiral band, and the pressure and wind direction change at the surface in relation to the movement of the spiral band agreed well with actual observations. The band seems to have both internal and external gravity wave modes.

In addition, the experiment with an axisymmetric model has been completed, and the results extensively analyzed. The budget analyses of relative angular momentum, vorticity, and energetics show the mechanism of the intensification of a weak vortex into a strong hurricane and its maintenance.

Measurements of decaying turbulence in homogeneous water were obtained using a stereo, photo-optical, particle tracer technique. Photographs of particle tracks (approximately 400 frames) were read by a photo-densitometer. A first reduction of the data yielded all three components of the turbulent energy throughout the decay process. Although the longitudinal energy seems correct, the transverse components were unrealistic; a detailed investigation revealed deficiencies in the code used to interpret the photo-density arrays in terms of velocity fields.

The earth's atmosphere is not the only one being modeled at the Princeton laboratory. An initial study of Jovian atmospheric dynamics has been completed, to test the hypothesis that the atmospheric circulations of Jupiter are a manifestation of large-scale convective instability brought about primarily by the presence of an internal heat source. The hypothesis was examined by deriving the nature of convection in an unstable rotating atmosphere.

The solutions obtained display many features coincident with the atmospheric ones, for example, the banded structure and zonal velocity field of the most realistic theoretical solution resemble the observed, having five zones and four belts each with its characteristic differential zonal motion. The solutions also indicate that a tropical westerly jet can be produced by an axisymmetric flow provided the Jovian atmosphere is relatively shallow (less than 500 kilometers), and that a strong equatorial westerly flow can occur provided that there is a strong diffusion of the tropical jet.

Diagnostic studies of the present climate based on a recent five-year sample of hemispheric upper-air data are being carried out by the laboratory with special emphasis on the year-to-year variability in the basic atmospheric statistics and climatic trends. Such statistics are needed to test the reliability of numerical simulations at the Geophysical Fluid Dynamics Laboratory and at other modeling groups. The data basis will be extended to cover a total period of 10 years, and will stress year-to-year variations in the statistics and possible 10-year trends in the climate.

A special project is analyzing climatic abnormalities during recent years. The simultaneous investigations of deviations from normal in the ocean surface temperatures as well as in snow and ice cover should provide clues as to possible causes of the atmospheric anomalies.

Two-week prediction experiments with the "1967 version" model have been made with twelve January and seven July cases, and the results analyzed collectively. The model is 9-level hemispheric, and the horizontal grid resolution is about 270 kilometers at mid-latitude. The conclusions reached so far are that the model shows some skill in predicting the flow fields for as long as 10 days in winter and a little longer in summer, but that the precipitation forecast is acceptable only for the first four days for winter periods (results are not yet known for summer). It is disappointing but interesting to note that the planetary-scale motion was not well predicted. If the horizontal grid resolution is increased (to 135 kilometers grid size), the model's performance is considerably improved for the five to 10 day range (based upon two cases); this is particularly true for the longer wave motions.

The boundary layer transfer processes have been tested by incorporating into the model the proposed elaborate formulations for vertical fluxes of momentum, heat, and moisture, as well as diurnal variation and heat conduction within the soil. In contrast to the earlier results with the low horizontal resolution model (540 kilometers grid size), the experiments with the finer grid model (135 kilometers grid size) show that the boundary layer physics have a noticeable effect upon the cyclone scale flow fields, and by the eighth day there is a substantial improvement in the predicted cyclone behavior.

Numerical simulation of the stratospheric sudden warming has been attempted for the third time. In the first try in 1967, a model with 270 kilometers grid size and nine vertical levels was used. While the breakdown of the circumpolar vortex was simulated successfully, the "strato-warming" itself was not reproduced. In the second attempt in 1969, sacrificing the horizontal resolution and increasing the vertical resolution, a model of 18 levels was applied, but the overall results turned out to be worse than those of the first case. Now the model is improved; the grid size is 135 kilometers and there are 18 levels in the vertical. The overall features in the stratosphere circulation and thermal structure were considerably improved but the simulation of a sudden warming was not quite satisfactory yet.

The "nested grid" model has been tested. The grid consists of a small domain with a fine mesh imbedded inside a larger domain which has a coarse mesh. For the test, the unfiltered barotropic equation was employed. The calculation was speeded up eleven times by using the implicit instead of the explicit method.

The effect of an equatorial boundary on wind and temperature at middle and high latitudes was studied by comparing two solutions; one called the "control" experiment is from a global model and the other is from a computation with the same model but with a "wall" at the equator. As was found by Baumhefner earlier, the effect is not appreciable before the eighth day. It seems, however, that after 12 days the equatorial boundary causes serious distortions in the overall solution.

Comparisons of the real and the simulated evaluate the constantly evolving models of the atmosphere "constructed" at the Princeton laboratory. Here, the surface time mean flow for July as computed (at left) and as observed by Y. Mintz in 1952, point up the generally good agreement possible between these two worlds.

Completing the Fluid Envelope

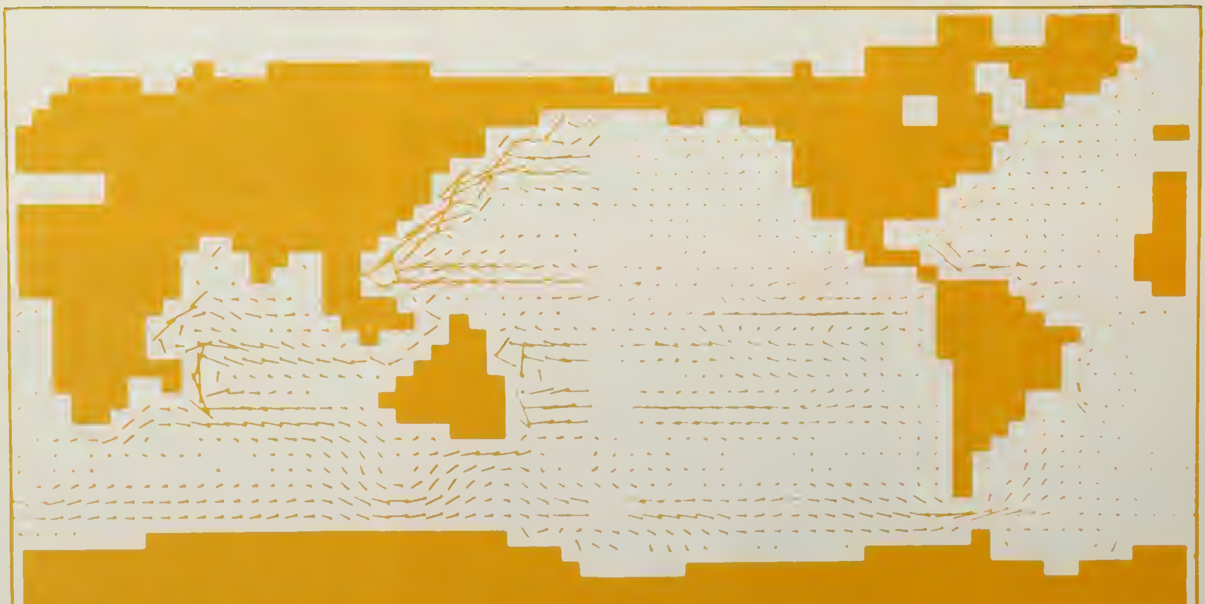
One of the principal results of the Geophysical Fluid Dynamics Laboratory effort has been to reinforce what scientists have always known — the ocean and atmosphere are fundamentally linked and processes in one cannot be modeled without considering events in the other. Thus, a crucial study at the Princeton facility is asking how seriously these two fluid systems are coupled to one another, and over what temporal scales. Several models have been developed ranging from global ocean-atmosphere models to mathematical composites which simulate processes at regional scales of motion, and bring the full planetary fluid envelope into the laboratory for experimentation.

Extended calculations have been carried out with the joint ocean-atmospheric model.* The ocean model covers the entire world ocean, and includes such features as bottom topography, temperature, salinity, and a method of predicting the growth and movement of pack ice in polar regions. Many modifications of the standard world ocean computer program were necessary for this climatic study. In the older program the world ocean was computed in three projections, one for the area between 60 degrees south and 60 degrees north, and two for the polar regions. This strategy was developed to overcome the troublesome problem of convergence of meridians at the poles when uniform-grid-based spherical coordinates are used. For the climatic model, however, it is more convenient to represent the entire world ocean in one projection based on a net of grid points separated by uniform increments of latitude and longitude. An efficient method for numerically integrating the dynamical equations on such a net has been developed, along the lines already tested for the atmospheric model. Fourier filtering is used along latitude circles to suppress the unwanted small-scale features that arise through the convergence of meridians.

The preliminary test run with the joint ocean-atmosphere model was based on a grid interval of about five degrees of latitude by five degrees of longitude. Although this mesh is too coarse for a realistic simulation of major ocean currents, several interesting features were brought out. To avoid bias the initial temperature and salinity fields were horizontally uniform over the entire global ocean. The entire numerical integration was equivalent to several centuries of time for the ocean. During that time horizontal gradients of temperature and salinity developed in response to boundary fluxes of heat and moisture determined by the stratospheric component of the model. At the end of the run a realistic thermocline configuration had formed, and most of the major surface currents of the world were simulated. An excellent feature of the solution is the characteristic difference in surface salinity between the Atlantic and Pacific. Tests during the computation also showed that a realistic depth of the thermocline could only be obtained for a vertical mixing less than 0.4 square centimeter per second, in agreement with recent evidence based on the observation of details of the temperature microstructure and tritium distribution in the upper ocean.

A regional study of the circulation of the Arctic Ocean and Greenland Sea has successfully simulated the formation of the main water masses of this region. The multilevel baroclinic model predicts a density structure and associated dynamic topography which verify quite well against the limited hydrographic data taken through the Arctic ice pack by Soviet, Canadian, and United States expeditions. The model predicts the formation of two separate gyres in the deep water on either side of the Lomonosov Ridge. The surface currents agree well with the observed pattern of ice drift over the Arctic Basin. It is hoped that the model will be useful in analysis of data from the POLEX program, an observational experiment under the Global Atmospheric Research Program for the Arctic region.

Joint Air-Sea Model



*In part supported by a National Science Foundation/International Decade of Ocean Exploration Grant.

The advent of the new computer will permit a greatly accelerated program for simulating the earth's climate with the joint ocean-atmosphere model. Smaller efforts are planned to improve the accuracy of the mathematical structure of the model, and a regional circulation study is being undertaken to extend the results of an earlier, very promising study of the response of the Indian Ocean to the changing monsoons.

Results of a diagnostic study of the general ocean circulation for the North Atlantic have been completed and study continues of the important effects of bottom topography and baroclinicity on the Gulf Stream transport in a study of an idealized ocean. The development of fine resolution models was begun in order to be able to compute explicitly the eddy fluxes of heat, salt, and momentum in the general circulation. Both two-layer and fully three-dimensional models have been formulated. A sequence of tracer experiments has been completed and the results are being brought together in a final report. Further tracer studies will be made when dynamical models which explicitly include eddy fluxes are developed.

Studies of the behavior of a stratified, three-dimensional model of the Equatorial Undercurrent have been completed, one using a three dimensional numerical model to explore the dynamic behavior of the undercurrent in several cases with different eddy viscosities, the other reviewing what is presently known about the oceanic circulation in the tropics.

Work continues on the construction of a fine resolution, three-dimensional regional model of the California Current System. Hydrographic data collected in the region of the California Current System are being analyzed to isolate and identify its characteristic features. A review of the literature concerning recent ideas on dealing with open boundaries in numerical models of geophysical flows has been made and it is planned to test some of these ideas using a simple two-dimensional model. The results of this study should be of general interest, besides being of particular importance to the California Current model.

With the arrival of increased computer power, the laboratory will examine the role of baroclinic instability in producing eddy fluxes of momentum, heat, and salt in the oceanic interior as well as in the western boundary currents. In addition, studies with realistic (transient) wind driving are planned to examine the role of directly generated eddies on the general circulation. The role of transients in the California Current region in which observations suggest that eddies play a major role is also being examined.

Idealized oceans are used at the Geophysical Fluid Dynamics Laboratory to simulate and predict real oceanic motions. At left, the motions of a kind of "swamp," an ocean 170 meters deep. Below, a more detailed study of circulation patterns in the North Atlantic ocean.

Advanced Scientific Computer

While it used its two UNIVAC 1108's, the Geophysical Fluid Dynamics Laboratory could run a day of mathematical weather in about 36 hours, with a resolution (or grid size) that restricted the model's detail. In 1971, a contract was let with Texas Instruments, Inc., for a fifth-generation system that would have eight times the computing power of the largest system then in use anywhere. This Advanced Scientific Computer promises to bring fluid dynamic models much closer to the natural events they simulate. The new system has the power to execute nearly 100 million instructions each second and will permit the further testing of predictive models that laboratory scientists hope will eventually extend global and regional weather forecasting out as far as several weeks into the future. The new computer also enhances the ability of these models to accommodate and test the mountain of data becoming available from the large area studies in the natural laboratory — for example, BOMEX, IFYGL, and GATE.

Remote Sensing — Data At a Distance

EVERYTHING WE SEE and sense comes to us through a narrow interval in the spectrum of electromagnetic energy or in the form of the vibrations we call sound. We go through life perceiving what we can — color, flash and shadow, sound and motion, and the properties of things — using a groping hand or probe of light when darkness brings our sensory limits in still closer.

What if our range were greater?

What if we could also "watch" in the infrared, sensing patches of warm and cold; or, gazing skyward at midday, we sensed the stellar radio sources? What if we could use our voices like the sonar of hunting porpoises and bats? There are worlds and worlds; and, gradually, science is teaching us how we may enter them all.

Remote sensing is the term used to describe this ability to observe our surroundings by passively listening or watching, or by probing with a burst or beam of energy. It is everywhere in nature, and it has come also to pervade environmental science, substituting the products of technology for the special adaptations we see in some creatures.

The "what-ifs" here are to the point: What if we could monitor wind fields inside the clouds, measure atmospheric constituents along a line of sight, detect the electrical signals of severe storms, measure wave motions on an oceanic scale, sense primary life as it assembles and disperses in the sea? Important questions, these, for they describe the poorly known borderlands of our ability to observe the environment and oceanic life.

In the Environmental Research Laboratories, a national center of excellence has developed in the field of remote sensing that has its origins in the Commerce Department's early concern with high-frequency radio propagation and its relationship to the ionosphere. The work of what is now the Wave Propagation Laboratory evolved by spreading out across the spectra of electromagnetic and acoustic energy, its focus shifting from radio propagation to the myriad observational uses of those spectra. At present the laboratory is stressing remote measurement of the atmosphere using microwave, infrared, optical, and acoustic waves, and exploring new concepts for monitoring events on and in the sea.

The Radio Eye

RADIO WAVES — electromagnetic energy with wave-lengths from about a millimeter on up — used to be something that could be heard but not seen, and that was where the emphasis lay in radio propagation research. Radar, a word made from "radio detection and ranging," changed all that, and made radio energy above the very-high-frequency range one of the commonest and most useful of visual aids. Radar operates by beaming out a pulse of radio-frequency energy, usually in the centimeter or millimeter range, then "listening" for the returning echoes of that beam. The travel time of the beam out and back, and the antenna direction, give range and azimuth to the target.

Scientists in the Wave Propagation Laboratory are extending this traditional use of radar. By applying Doppler techniques — that is, by analyzing the changes in frequency of its returning echoes, caused by motion of the target with respect to the antenna — they have been able to extract considerable environmental intelligence from this part of the spectrum.

A meteorological Doppler radar system, using two transportable three-centimeter wavelength systems (not the larger, 10-centimeter systems operated by the National Severe Storms Laboratory), has demonstrated its ability to provide many times the windfield information available from previous instruments. Dual Doppler radars, operating with such targets as snow, stratiform rain, convective cells, and chaff, have obtained wind-field measurements with an accuracy that reveals small-scale details of the velocity field. The two radars operate synchronously so that both antenna axes sweep a common plane; this permits the use of two-dimensional data to construct a three-dimensional view of the velocity field. The instruments also provide data which can be used to calculate turbulent energy dissipation and momentum fluxes for a wide variety of meteorological conditions, demonstrating the utility of Doppler radar for boundary layer studies.

Much of the emphasis here is on the study of convective storm dynamics by simultaneous observation of the same storm from different Doppler radar installations. This has included observations made in conjunction with the National Hail Research Experiment, which produced uniquely useful three-dimensional wind fields at numerous levels through observed storms. A frequency-modulated continuous wave radar is being constructed for use in boundary-layer clear air turbulence studies. This system should eventually lead to a high-resolution radar with Doppler capability in clear air.

New radars are entering the field as the Wave Propagation Laboratory's remote-sensing concepts take form as hardware. At left, a new FMCW (Frequency Modulated Continuous Wave) radar for probing atmospheric structure in clear air. And below, one of a pair of 3-centimeter Doppler radars

An important newly developing program area is investigating the use of skywave radar to sense distant sea-state. A knowledge of the state of the sea — as represented by waveheight, wave period, and wave direction — would benefit several classes of users. Maritime shipping and fishing industries can plan more efficient operations at lower risk with such information on a routine basis. And, because of the relationship between wave characteristics and the surface wind history, this information would be a very useful input to global weather prediction programs. Monitoring the development of storm-created heavy seas can yield forecasts of potential wave damage to coastal areas. Finally, unresolved problems in oceanographic and atmospheric science — such as the dynamics of the air-sea interaction — can be studied if one can accurately measure sea state.

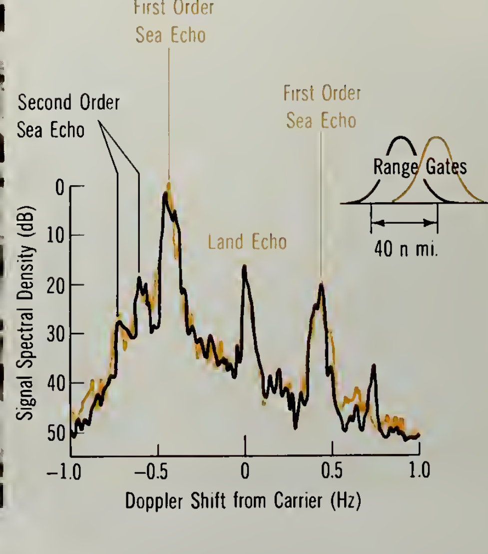
The purpose of the sea scatter program within the Wave Propagation Laboratory is to develop and demonstrate those remote sensing techniques which can measure sea state. Included are techniques which can both monitor wave conditions over very large expanses of ocean, and also localized sensors which can provide more detailed wave statistics in special areas. The former category includes high-frequency skywave (ionospheric) radars and short-pulse satellite microwave altimeters. The latter category includes ship-or buoy-mounted medium frequency/high frequency radars.

At present, primary emphasis is being given to the development of the high frequency skywave radar technique. In operation, two stations within the United States could routinely monitor waveheight, period, and propagation direction from our coasts out to about 2,500 kilometers in a grid of range cells spaced 30 by 30 kilometers. The observable that yields the desired wave information is the second order Bragg-scattered received Doppler signal spectrum. Both theory and ground wave experiments show that the magnitude and shape of this echo depends on the waveheight directional spectrum.

A theoretical model has been developed relating the ocean waveheight directional spectrum to the scattered first- and second-order high-frequency Doppler signal spectrum. This model shows that the second order signal spectrum varies in shape and amplitude with the sea waveheight spectrum. This second-order echo is produced by the simultaneous interaction of two trains of ocean waves and the incident radar wave. Extensive groundwave measurements of high frequency sea backscatter have been made in the Pacific from San Clemente Island. Wave Propagation Laboratory personnel are now in the process of reducing these data and comparing the results with the theoretical model. Very preliminary results show good parametric agreement between radar signal spectra and the predicted signal spectrum based upon sea-state conditions measured in the scattering area.

In a small program with the National Aeronautics and Space Administration, the signal received in a short-pulse altimeter is being analyzed to ascertain the degree to which waveheight, wave period, and wave propagation direction can be routinely monitored by this technique. A model relating ocean waveheight to the shape of the received signals from a short-pulse altimeter has been developed at the Wave Propagation Laboratory. The model has been verified against aircraft altimeter measurements over the ocean.

Observing sea-scattered signals from a skywave (ionospheric) radar holds great promise for ocean remote sensing, particularly the second-order echoes, which appear to provide the entire wave size and direction spectrum for the patch of sea under observation. At left, a skywave radar antenna installation of the type used in these experiments.



Listening in Microwave and Infrared

The alternative to probing the environment (as is done with radar, for example) is to listen to it at certain crucial frequencies. The Wave Propagation Laboratory's program in environmental radiometry is learning to translate what is heard in the radio wave and infrared regions of the spectrum — electromagnetic energy at wavelengths from many meters down to the 8,000-Ångstrom boundary with visible light — into important atmospheric information.

Emphasis here has been placed on radiometric methods that observe the natural thermal emission from atmospheric constituents and on the radiation from discharge processes that occur in thunderstorms. The former is specifically applied to the measurement of temperature, water vapor, and liquid water in the atmosphere, while the latter is being studied as a possible means for detecting the presence of tornadoes associated with severe storms.

Studies of the mathematics of profile inversion are continuing. The techniques developed are essential to retrieve a maximum of information from many of the radiometric measurements, but are also being applied to a variety of remote sensing problems. A complete theory of iterative solutions of linear operator equations has been derived, and the resulting methods incorporated into the Skylab Program. The Backus-Gilbert inversion technique has been applied to several problems, including retrieval of particle size distributions from optical scattering measurements, temperature profiles by ground-based microwave radiometry, and temperature and water vapor profiles by ground-based or satellite-borne infrared radiometers. A study is being made of the degree to which tropopause heights can be obtained from infrared radiances.

A joint experiment to compare ground-based microwave and infrared techniques for passive remote sensing of temperature profiles has been conducted at White Sands Missile Range, New Mexico. Additional experiments to determine the applicability of the microwave measurements to temperature structure estimates in the boundary layer have been carried out at Haswell, Colorado.

Earlier radiometric data obtained at 20.6 GigaHertz in Hawaii showed a high degree of correlation between atmospheric emission and the line integral of refractive index over a 65-kilometer mountain top-to-sea level path. More recent measurements on an absolute basis have indicated very good quantitative agreement between independent measurements of the contribution of water vapor to the integrated refractive index and direct measurements of the water vapor itself.

A search for electromagnetic signatures suitable for tornado detection has been conducted for several years. Initial observation of radiation from lightning discharge processes in the frequency band from 10 kiloHertz to 137 MegaHertz indicated that most tornadoes showed unusual electrical activity at frequencies above 500 kiloHertz. This activity is characterized by a relatively large number of bursts per minute of high rates of large amplitude electromagnetic impulses. Data from 15 tornado detectors deployed in "tornado alley" in 1972 indicate that about 73 percent of the tornadoes within range of the instruments were detected, and that about 7 percent of the local thunderstorms produced false alarms. Additional data of this kind are being collected, and improved instruments with direction-of-arrival capability have been deployed. It is hoped that these sensors, when fully operational, will significantly reduce the time between detection, warning, and emergency action by the appropriate public agencies.

Several research projects in this program area produce techniques for remote sensing of properties of clouds. These techniques are expected to be useful in monitoring the effects of artificial cloud modification and the advection of water in water budget studies, and in determining the adverse effects of clouds on other remote-sensing techniques. Computations of microwave thermal emissions from various cloud configurations have been used to explore some of the possibilities and difficulties associated with water content measurement. Recent measurements at 31 GigaHertz show excellent sensitivity to liquid water and rejection of ice in small-particle stratus clouds; during a snowstorm the integrated liquid thickness in the vertical was observed to range from less than 0.02 millimeter up to about 0.1 millimeter.

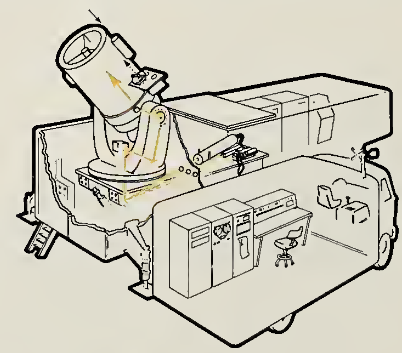
An electromagnetic tornado detector has completed several successful seasons in experimental installations, and has evolved into a unit capable of sensing both the electrical signature associated with tornadic storms and the 45-degree azimuthal sector from which the signals emanate. At far left, the Union City, Okla., tornado of 1973, which was detected by the Oklahoma City detector.

The Light Fantastic

Much of the remote sensing research in the optical region of the spectrum — the frequencies between about 400,000 and 800,000 GigaHertz — is tied to experimental lasers, the mid-twentieth century tool that seems to have applications everywhere in science. Lasers have the unique and interesting property of being able to transmit a beam of coherent light in a narrow frequency band, in the same way that a radio antenna transmits a narrow-band signal of radio-frequency energy. Because our eyes are sensitive to optical radiation, lasers are unusually beautiful, transmitting beams of red, or blue, or green, or violet light that is so coherent as to seem fluid. But they are also immensely utilitarian, as the Wave Propagation Laboratory's work with optical and near-infrared systems has begun to demonstrate.

Theoretical and experimental studies of the interaction of electromagnetic waves, at optical and near-infrared frequencies, with the lower atmosphere are being conducted for remotely sensing atmospheric temperature, wind, and turbulence, and in support of the design of optical communications systems, imaging systems, and a variety of special-purpose systems such as target illuminators. For example, the integrated horizontal wind speed blowing across a line of sight can be measured by appropriate spatial filtering and correlation of the scintillation pattern of a laser beam directed from a source to two detectors separated horizontally by a few centimeters. This method has been successfully tested on a 1-kilometer test range and on a 15-kilometer path near Boulder.

Immediate plans concern the extension of the average wind-sensing technique to permit the observation of the profile of the crosswind at various portions of the laser-beam path. Tests are being developed to explore the possibility of replacing the laser source by natural illumination including, for paths through the upper atmosphere, the sun, moon, and stars. Further study is needed to assess the effect of extreme levels of turbulence (the saturation effect) on the optical wind sensor.



A two-color optical distance-measuring device has been developed and tested that has a demonstrated precision of three parts in 10 million, better than any presently available device. The instrument promises to have important applications in geodesy, in geophysical studies of the motions of the earth's crust, and in studies of earth deformations associated with earthquakes.

Theoretical, laboratory, and field research are being conducted on the use of the spectral characteristics of constituents of the earth's atmosphere to measure remotely the parameters of the atmosphere. These activities support atmospheric science, weather prediction and modification, pollution detection, and measurement of atmospheric turbulence. Emphasis is on spectroscopic techniques applied to atmospheric gases, hydrometeors and lithometeors, and pollutants.

The Raman lidar technique relies on the back-scattered radiation from molecules that, by its frequency, provides precise chemical identification. This method has been tested against meteorological instruments on towers and proven to be effective in measuring profiles of temperature and humidity. The range is limited, with present-day practical field laser systems, to a few kilometers, and studies of alternative methods of potentially greater

This versatile remote-sensing system permits simultaneous soundings of the atmosphere with a multi-wavelength lidar, microwave radar, and infrared radiometer. The van-mounted system is being used to measure clouds and mountain lee waves, air pollution constituents, and other atmospheric properties.

Most of the new optical techniques rely on several principles relating to the interaction of light with particles. Some of the most important ones are:

- **RAMAN SCATTERING. Molecules in a solution — including molecules in the atmosphere — scatter light and cause an alteration in the wavelength of the light. The kinds and quantities of molecules in the atmosphere can be deduced from measuring the wavelengths and amounts of backscattered light. Wave Propagation Laboratory scientists have used Raman scattering to measure pollutants emitted from smokestacks.**

- **MIE AND RAYLEIGH SCATTERING. Spherical particles scatter light in certain consistent ways dependent on the wavelength of the light and the size of the particles. Light of known wavelengths can be used to deduce the size of spherical particles — such as water droplets and some natural and man made particles — in the atmosphere when the light is backscattered to sensors.**

- **MOLECULAR ABSORPTION. Light passed through a medium is absorbed by molecules in the medium. The absorption occurs in definite wavelengths according to the molecules present. If white light (a mixture of many wavelengths) is passed through a medium containing various molecules, then is resolved into its spectral components, there will be gaps in the spectrum representing the absorbed wavelengths. The kinds and amounts of molecules are deduced from these gaps.**

Likewise, if light in a single wavelength which corresponds to the absorption range of a particular molecule is passed through a medium containing this molecule, then there will be an attenuation of the light due to absorption. Because each kind of molecule has this "signature," or spectral absorption region, lasers which are tunable over several of these signatures will enable scientists to analyze the atmosphere for a number of pollutants. The signatures of the most common pollutants — carbon monoxide and sulphur oxides — are known and others are being compiled. The molecular absorption technique is highly sensitive, and may be useful for precise averaging of ambient pollution over long horizontal distances in urban areas.

sensitivity have been undertaken. These include the differential absorption method, which is best accomplished by the simultaneous transmission of two frequencies one on and one off an absorbing region of the molecular spectrum. The ratio of attenuation is then a measure of the amount of the constituent. Among other methods studied theoretically is the infrared fluorescence of some atmospheric molecules, particularly water vapor.

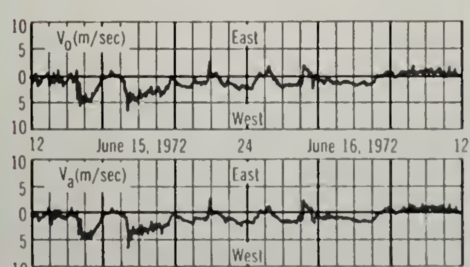
The measurement of wind velocity has moved from eddy correlation methods, which relied on the measurement (by the scattering of laser radiation) of the passage of aerosol inhomogeneities, to the use of Doppler techniques. These techniques are similar to microwave Doppler radar, but use infrared or visible lasers with the advantage that signals may be obtained from the tracers of the atmospheric motion, namely aerosols, and also that excellent angular and spatial resolution may be obtained. The optical Doppler technique is expected to find application in the study of vortex phenomena, from dust devils to tornadoes, and in organized mesoscale phemomena such as helical rolls, plumes, and mountain lee waves.

The scattering of radiation from aerosols and hydrometeors of the atmosphere has been studied in the laboratory and in the field in order to provide information on the character of clouds and other obstructions to visibility. The temperature, the liquid water content, the ice or snow content are of importance for weather forecasting, for assessing cloud modification, and for airport weather advisories. A multiparameter approach, in which wavelength, angle of scatter and observation of on-frequency and displaced frequency scattering are analyzed, gives the most promise for remote sensing of these important quantities.

Resonance Raman effects are often many orders of magnitude larger than the ordinary Raman spectra. In some materials of biological importance in the oceans, namely chlorophyll and β-carotene, a very strong resonance Raman scatter has been detected which can be used for the detection of these materials in the ocean.

Under a recent agreement with NOAA's National Weather Service, the Wave Propagation Laboratory is conducting an analysis of the potential of lasers — and particularly of lidar, the laser equivalent of radar — for operational remote sensing of various natural and manmade atmospheric phenomena. A high-power, four-wavelength lidar system has been constructed for experimental evaluation of the role of lidar in atmospheric remote sensing. Some of the specific atmospheric measurements under consideration are pollutants at emission sources, gaseous pollutants in the air, suspended particulates and aerosols, and concentrations of various atmospheric constituent gases.

A wind-sensing laser device provides velocities of winds across a line of sight. Binoculars receive laser light from several kilometers away, and scintillations of the laser beam are translated into wind values. Close correlation between remote and direct measurement of winds is shown below, with laser-measured values in color.



SENSING WITH SOUND

USING THE COMPRESSIONAL vibrations of sound to sense conditions in the atmosphere is both older and newer than the electromagnetic wave sensors — although a kind of early echo sounder was used to probe the atmosphere in the 19th century, it has only in the last several years come close to routine operation, even in the research sense.

The Wave Propagation Laboratory's atmospheric acoustics program is identifying and applying the unique advantages of acoustic waves to the study of atmospheric properties and processes. Theoretical studies are analyzing various research opportunities, to understand more completely the propagation of acoustic energy in the turbulent atmosphere, and to determine unique signatures imparted to the transmitted or scattered acoustic energy by the temperature, humidity, or wind structure of the atmosphere. Acoustic echo sounders have been designed, constructed, and used to evaluate how well acoustic systems can be applied to determining the spatial and temporal properties of atmospheric variables. Because of the experience gained in analyzing, designing, and experimenting with acoustic equipment, the program finds itself in strong position to design or specify acoustic systems to solve significant problems within NOAA and other government agencies. Engineering models of possible prototype operational equipment are being constructed and tested to investigate possible acoustic solutions to these problems.

Theoretical studies have resulted in the derivation of an expression for the spectral bandwidth of a scattered acoustic wave as it is affected by turbulence structure and mean wind field refraction. It has been shown that the present Doppler measurements are affected only in the second order by such effects. If longer range sounding, beyond one kilometer, becomes feasible, refraction effects may become important in interpreting the Doppler shift for wind field mapping.

A highly simplified "Sounder-in-a-Suitcase" has been developed and tested. The portability of this unit makes it quite feasible to enter quickly into field exercises. This advanced design, based on all-digital logic has proved to be extremely reliable during several extended field operations.

A sounder was placed in operation in the Middle Park region of Colorado near Fraser during the winter months of 1972-1973 to monitor the height of stable layers forming in the high mountain valley. This unit presented challenging engineering problems in that provisions for snow melting and removal had to be provided, shielding from wind noise in the surrounding pine trees was necessary, and shielding and damping of the antenna were needed to avoid annoying nearby permanent residents in the extremely quiet mountain valley. Inversions were detected to heights of greater than one mile above the site, or at heights exceeding that of the Continental Divide, immediately to the east of the sounder site. Single-axis Doppler wind sensing will eventually be used here to measure wind and wind shear conditions above Middle Park, of importance in predicting severe lee slope (or "Chinook") winds.

Acoustic sounder methods have now been employed to provide new information on the heat flux and wind field in thermal convective plumes, which is not available using any other method. The continuity of the wind fields, showing convergence at low levels into the plumes and divergence aloft at the remnant of the nocturnal radiation inversion, is clearly depicted using three-axis wind sensing by means of the acoustic sounder. Additional tests have been made using an array of sounders to measure the vorticity in the planetary boundary layer during thermal plume and dust devil conditions. The strong interaction of the atmospheric angular momentum with the earth's surface has been proven from preliminary data analysis. Using the same array of sounders, the bistatic return caused by mechanical turbulence in the atmosphere has also been measured and found to provide a far stronger acoustic scattering target than previously available using monostatic systems. This same data set is providing information on heat and momentum flux through the planetary boundary layer by application of eddy correlation techniques.

The growth of atmospheric acoustic programs in other institutions has been so rapid in the past several years that it was considered timely to hold an international workshop to discuss progress in the discipline. Sessions lasted for two days during July 1972, and participants from 77 institutions reported on the status of the 25 programs which have been identified around the world.

To extend the utilization of acoustic echo sounder techniques and encourage the transfer of remote sensing

Acoustic sounder system developed by the Wave Propagation Laboratory measures wind velocities and wind shear up to about 500 meters' height. Searchlight-mounted sounder is one of three speakers in the system. Sonic pulses and backscatter appear on oscilloscope in van, where a minicomputer converts them into real-time wind and windshear profiles.

technology to user communities, a monostatic sounder was operated next to the National Weather Service Environmental Meteorological Support Unit in Denver during the winter and spring months of 1971-1972. Sounder records obtained were compared with radiosonde measurements of temperature and wind. A paper has been prepared describing the advantages of such joint instrumentation for monitoring the structure and dynamics of ground based and elevated temperature inversions which trap pollutants in built-up city areas.

Tests are continuing of the suitability of the sounder for augmenting air pollution monitoring and prediction sensors by placing a sounder in operation in the Los Angeles basin, with the output recorder in the Weather Service Forecast Office there. The sounder will incorporate a slanting beam to provide one axis of Doppler derived winds along the predominant sea-breeze ventilation direction.

In addition, the development of a wind and wind-shear sensing acoustic Doppler system was initiated with support from the Federal Aviation Administration. This system has been installed at Denver's Stapleton airport after check-out and calibration at field sites in the Boulder area. The system incorporates five acoustic antennas in two orthogonal planes to detect the bistatic scattering of sound from heights of 30 meters to 500 meters in 30 different height increments. This system employs a minicomputer to compute the winds in each height interval. Critical wind-shear information will be relayed to the control tower over a dedicated telephone line.

After a period of evaluation, a report has been prepared for the Federal Aviation Administration detailing the results and concluding that the acoustic system shows promise of being able to perform the needed operational function of wind shear warning. A three-axis wind-sensing sounder is being developed for deployment on one of the NOAA ships in the GATE experiment.

Most of the acoustic echo sounding to date has been accomplished within the planetary boundary layer, or to heights of one kilometer. A much larger sounder is being developed to operate at much lower frequencies, and sound to heights of five or six kilometers in the Boulder area. This should provide a tool for monitoring lee-wave wind phenomena, and will help determine whether sounders have eventual application in high-altitude clear air turbulence studies.

In the area of geoacoustics research, the laboratory has continued its efforts to identify natural sources of the very low frequency vibrations called infrasound, especially that emitted by severe convective storms. This project is attempting to discover how and why certain convective storms emit infrasound detectable more than 1,000 miles away, and see whether the emissions have any practical value, for example, as advance indicators of storm severity.

A study of infrasound received at the Boulder observatory during the 1972 storm season showed 86 wave arrivals that apparently originated in severe storms in 17 states, mostly in "tornado alley." A relatively large fraction (52 percent) of the emitting storms produced confirmed tornadoes. A larger fraction (78 percent) of the emitting storms produced documented severe effects of some kind (large hail, heavy rain, high winds, tornadoes). A few cases of emissions from long-lived storms suggest that infrasound may be a good advance indicator of storm severity, in the sense that the emissions apparently originate in storms that are longest lived and produce the severest effects.

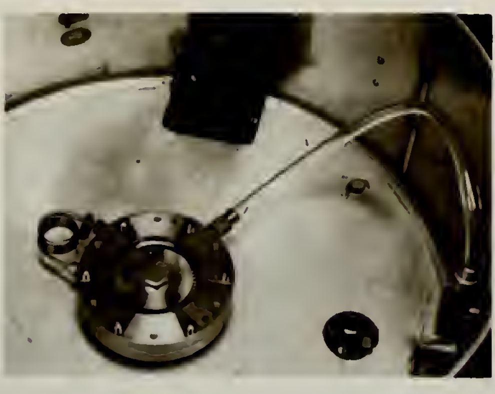
Efforts to uncover the physical emitting process have combined theoretical modeling of various 'reasonable' candidates with detailed analysis of selected events. For example, frequency and directional spectra reveal rapid changes in apparent source location and frequency content. Several 'obvious' candidates have thus been eliminated. It now appears that the emissions are related to the intense concentrations of vorticity that form in some storms.

Because of uncertainties associated with source identification from a single observatory, and because meteorological "noise" causes sensor outages, two more observatories were deployed, one near Albuquerque, New Mexico, and the other in Rapid City, South Dakota. This additional observing capability permitted the location of most of the emitting storms between the Rockies and the Mississippi during the 1973 season. It also provides a data base for experiments with simulated "storm-warning" situations.

Study of pressure and wind velocity fluctuations associated with gravity wave motions in the planetary boundary layer has continued. These measurements have been used to compute directly the wave phase velocities and to help confirm that a number of the waves thus far observed are generated by shear instability in the boundary-layer airflow. In addition, the measurements have been used, together with acoustic-echo-sounder and other forms of data, to estimate the wave-associated vertical fluxes of momentum and energy in these cases. The results are preliminary, but suggest strongly that these fluxes are large, both in terms of the dynamics of the boundary layer itself and with regard to global atmospheric momentum and energy budgets. Definitive experiments to clarify the role of wind shear and wave instability in the dynamics of the atmosphere are being undertaken.

A similar case study of mesoscale pressure fluctuations associated with wave generation by shear instability in an upper troposphere baroclinic zone over the eastern seaboard, together with analysis of radar photos of the same wave event provided by a National Aeronautics and Space Administration radar on Wallops Island, has yielded similar conclusions concerning the dynamical role of such events.

Infrasound, the vibrations too low in frequency for us to hear, is being explored as an indicator of gravity waves, apparent prime movers in the atmosphere, and as a way of detecting air turbulence and distant severe storms.



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